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About using Serious Games to teach (Portuguese) Sign Language

Dissertação para obtenção do Grau de Mestre em Ciências de Engenharia Eletrotécnica e de Computadores

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“Your success and happiness lies in you. Resolve to keep happy,
and your joy and you shall form an invincible host against difficulties.”

– Helen Keller

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Abstract

Sign language is the form of communication used by Deaf people, which, in most cases have been learned since childhood. The problem arises when a non-Deaf tries to contact with a Deaf. For example, when non-Deaf parents try to communicate with their Deaf child. In most cases, this situation tends to happen when the parents did not have time to properly learn sign language.

This dissertation proposes the teaching of sign language through the usage of serious games. Currently, similar solutions to this proposal do exist, however, those solutions are scarce and limited. For this reason, the proposed solution is composed of a natural user interface that is intended to create a new concept on this field.

The validation of this work, consisted on the implementation of a serious game prototype, which can be used as a source for learning (Portuguese) sign language. On this validation, it was first implemented a module responsible for recognizing sign language. This first stage, allowed the increase of interaction and the construction of an algorithm capable of accurately recognizing sign language. On a second stage of the validation, the proposal was studied so that the pros and cons can be determined and considered on future works.

Keywords:

Natural User Interface

Sign Language

Serious Game

Kinect Sensor

Image Processing

Resumo

Língua gestual é a língua usada na comunicação dos surdos. Maioritariamente aprendido desde nascença, esta língua pode ser um entrave na comunicação com não surdos. Como por exemplo, na situação de país que tentam comunicar com o seu filho surdo. Quando esta situação ocorre, os pais dispõem de pouco tempo para aprender a língua de forma correta.

Assim, esta dissertação propõe o ensino de língua gestual (portuguesa) através de jogos sérios. Atualmente existem algumas soluções para esta proposta, contudo, essas soluções são limitadas. Por esse motivo, é adicionada uma interface natural com o intuito de explorar o campo dos jogos sérios numa nova perspetiva.

A validação deste trabalho consistiu na implementação de um protótipo de jogo sério, usado para o ensino da língua gestual (portuguesa). Na primeira fase desta validação, foi implementado um módulo para o reconhecimento da língua gestual. Isto permitiu com que se aumentasse a interatividade com o protótipo e a criação de um algoritmo capaz de reconhecer fidedignamente língua gestual. Na segunda fase da validação, a proposta foi estudada de forma a se obter prós e contras que possibilitassem a evolução deste protótipo para algo que possibilite o ensino de língua gestual.

Palavras-chave:

Interface Natural

Língua Gestual

Jogos Sérios

Sensor Kinect

Processamento de Imagem

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List of Abreviations

DA – Data Acquisition

DGBL – Digital Game-Based Learning

GUI – Graphical User Interface

HV – Hand Variation

IDE – Integrated Development Environment

IIGC – Intel's Interactive Gesture Camera

KB – Knowledge Base

KNN – K-Nearest Neighbour

NUI – Natural User Interface

RGB – Red Green Blue

ROI – Region of Interest

SDK – Software Development Kit

SG – Serious Games

SL – Sign Language

SLR – Sign Language Recognition

SVM – Support Vector Machine

U.S. – United States

WFD – World Federation of the Deaf

WHO – World Health Organization

WPF – Windows Presentation Foundation

1. Introduction

The focus of this dissertation is the proposal of teaching (Portuguese) sign language through the usage of serious games. Can you imagine having a deaf child and, at the same time, trying to learn a new form of communication in order to speak to that child? Well, this dissertation is intended to ease the sign language learning process, for non-deaf, while pursuing a normal daily life.

1.1 Global focus

According to the World Health Organization (WHO), over 5 percent of the world's population – 360 million people – has disabling hearing loss (Organization, 2013). And, from those, approximately 70 million are considered Deaf (Deaf, FAQ, 2014). As an example, Portugal has about 120 thousand people that suffer from hearing loss, from which, 30 thousand are considered sign language natives (Surdos, Comunidade, 2011).

According to The World Federation of the Deaf (WFD) "Human rights are universal and they belong to everyone regardless of sex, national or ethnic origin, colour, religion, language, or any other status such as disability or deafness" (Deaf, Human Rights, 2014). Nevertheless, due to societal prejudices and barriers, Deaf people are often overlooked. In an attempt to mitigate that, WFD set four basic factors to the protection of the Deaf human rights.

- First, the natural language of Deaf people, in each country, is **Sign Language** (SL). Here, just like spoken languages vary among countries, sign language also does. Thus, natural sign language is considered as a part of each "country's cultural, social, historical and religious heritage" (Deaf, Human Rights, 2014). A form of acknowledging this factor and contributing to the protection of the Deaf human rights is by recognising sign language as a natural language. Portugal, on 1997, was one of the first countries to recognize, by constitution, sign language[1] as a natural language (Surdos, Língua Gestual, 2011).
- The second factor is **Bilingual Education**. In this form of education, students learn two languages from younger age. As it has been showing good learning results, bilingual education is becoming more popular. "It supports the natural learning and communication environment of a Deaf child" (Deaf, Human Rights, 2014). This type of education includes "signacy", the sign language, "literacy", the written language, and "oracy", through both oral communication and fingerspelling of words (University, 2014).
- **Accessibility**, the third factor, is a reference to the barriers that lie in the lack of accessible information (Deaf, Human Rights, 2014). This is generally defined in two ways: 1 – direct interaction with other people, where accessibility often depends on sign language interpreters; and 2 – from other sources, such as mass media or documents, where WFD defines that Deaf people have the right to obtain information in sign language.

[1] In Portugal case, it was the Portuguese Sign Language (PSL).

- The last factor is **Interpreting**. WFD state that, when accessing services, in which the personnel do not use sign language, Deaf people have the right to a sign language interpreter (Deaf, Human Rights, 2014).

These four factors can be combined as shown in Figure 1.1. This means that sign language is at the core of a Deaf person life. Also, the other three factors fit together providing recognition and respect for Deaf culture and identity, therefore, achieving “full enjoyment of human rights” (Deaf, Human Rights, 2014).

Figure 1.1 – Deaf Rights Representation (Deaf, Human Rights, 2014)

In order to achieve this “full enjoyment of human rights” these factors must connect. Nevertheless, gaps still exist, particularly on interpretation. For instance, a hearing person that relies on auditory information finds learning this new language to be more challenging (Berke, 2010).

1.2 Dissertation Objectives

Considering the gap on interpretation, the main purpose of this dissertation is to tackle this gap and provide an alternative approach for teaching sign language. More accurately, this dissertation will be focused on supporting (Portuguese) sign language education to non-deaf, through the usage of serious games.

Therefore the fields of interest for this study are:

- Sign Language (SL), since it is expected to be provided an alternative embodiment to teaching sign language;
- Serious Games (SG) is the field that provides the alternative environment. This is due to the few existing formats for teaching sign language to non-deaf;
- Natural User Interfaces (NUI) is a field used to support the study, in which the features of turning the serious game truly interactive are obtained.

Taking benefit from these three fields, this dissertation intends to smooth the learning process of sign language, by providing a module of a serious game that uses a NUI sensor, used to recognize sign language.

1.3 Research Methodologies

According to the objective of the study, the research is based on the development of a serious game, used as an alternative source for education. In order to make this study, human participants will take part in the validation of two aspects of the proposed model:

- The sign language recognition system, where a quantitative study is done. This is made in order to select the best recognition system to be used on the model; and
- A prototype of the serious game, which is validated through a qualitative study, where questions like "Is the prototype useful to learn sign language?" are made.

For that reason, the validation consists of verifying the sign language recognition system and, afterwards, the serious game prototype. Nevertheless, despite some limitations on the sign language recognition system, the validation is expected to determine good results on the concept of the prototype and the usability.

1.4 Dissertation structure

After this introduction chapter, the document is organized as follows:

- Chapter 2: State of the Art
  A study on the fields of Serious Games and Natural User Interfaces are shown in this chapter, where concepts and examples are presented. Also, it is demonstrated the connection between these fields and Sign Language.
- Chapter 3: Proposal
  During this chapter, a solution to the presented problem is proposed. Therefore, a model for this solution is presented and an architecture of a prototype is described.
- Chapter 4: Implementation
  The implementation of this solution is described during this chapter. Firstly, the tools required for the development of the solution are presented here. A deeper approach is made to the solution, by including main algorithms and modes of play.
- Chapter 5: Validation
  The validation methods, the obtained results and some conclusions are addressed here.
- Chapter 6: Conclusions
  In this last chapter, a review of the developed work is conducted, identifying the main findings and providing a list of aspects that need to be improved as well as possible solutions for them.

2. State of the Art

According to the dissertation objective, the intent of this chapter is to explore the state of the art on SG and on NUIs, the main areas of research on the subject. For those two subjects a brief overview is provided, explaning some of the concepts, some examples are shown and, to conclude, the sign language application, on both fields, is explored.

2.1 Serious Games

"Serious games have become both a growing market in the video games industry (…) and a field of academic research (…)" (Breuer & Bente, 2010). In fact, new technologies are pushing firms to produce game-based or alike products and services, including both for professional and leisure markets (Stewart & Misuraca, 2013). Furthermore, these products and services are used in a broad spectrum of application areas (e.g. military, healthcare and education). According to this trend, serious games have been also used in evolving "edutainment"[2] for educational purposes (Susi, Johannesson, & Backlund, 2007).

The purpose of this section is to study serious games and, in particular, language serious games. Being considered a controversial concept, it will be clarified what serious games are and some related concepts. Other important aspect is the application areas. Here, some of those areas are studied and examples provided. To conclude the section, language education is also subject of study. From it, examples of sign language games are presented.

2.1.1 Concept Overview

The serious game industry is a very small part of the videogame industry, often dismissed as irrelevant or as not the 'real thing' (Stewart & Misuraca, 2013). Nevertheless, the serious game industry is starting to carve out a distinct identity. Despite the multiple definitions referred by (Susi, Johannesson, & Backlund, 2007), a core meaning is established. According to these authors, "serious games are (digital) games used for purposes other than mere entertainment".

This definition to the term 'serious games' means that similar concepts, such as 'edutainment' or 'e-learning, overlap.Furthermore, the game industry still prefers to use the term 'applied gaming', when referring to 'serious games' (Stewart & Misuraca, 2013).

Figure 2.1 is a good example on how the concepts around serious games overlap. According to (Breuer & Bente, 2010), "this figure is the result of the comparison and combination of different definitions and classifications (…)". In this figure six relevant terms are shown:

1. Entertainment Education, referring to any attempt to make learning enjoyable;
2. Game-Based Learning, a subset of Entertainment Education, which includes the use of any type of games for learning/education purposes;

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[2] Entertainment designed to be educational.

3. Serious Games, not restricted to education and learning, are also being applied in areas such as healthcare or advertising;
4. Digital Game-Based Learning (DGBL), is a substrate of serious games, where education and learning are its main purposes;
5. Classical Edutainment Games focus on video games with educational aim targeted to preschool and young children. This sort of games was very popular during the 1990s (Susi, Johannesson, & Backlund, 2007);
6. E-Learning, different from the other concepts, is referred as the combination of digital media and learning, where it might not be entertaining (e.g. podcasts of lectures or computer-based online examinations).

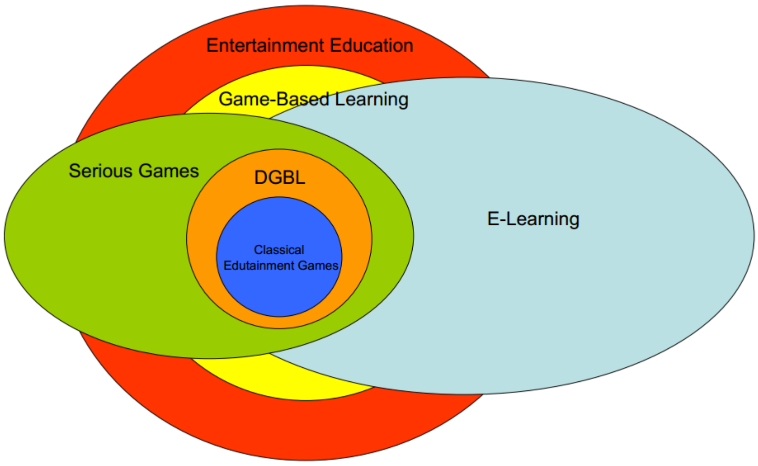


Figure 2.1 – Relations between serious games and similar educational concepts (Breuer & Bente, 2010)

Despite these definitions, the “Serious Game” term still raises great controversy. Some of the reasons are that this term can be treated as a marketing idea or the definition of a market with a distinct set of products, services, firms and approaches (Stewart & Misuraca, 2013).

Furthermore, other internet sources offer other definitions for this term. Nonetheless, an agreement point, between most definitions, is defined as “serious games are concerned with the use of games and gaming technology for purposes other than entertainment” (Susi, Johannesson, & Backlund, 2007).

2.1.2 Application Areas

Just like for the term ‘serious game’, the application areas can be categorized in many different forms. Therefore, the following are described according to the categorisation provided by (Susi, Johannesson, & Backlund, 2007). Inthis sense, the categorization is made by the main application field (e.g. healthcare or marketing). As examples, games are used in military, education and healthcare areas.

- **Military Games**

The concept “serious games” is relatively new. However, there is a long history on using serious games within the military. Some of the oldest examples are *Chaturanga*, a board game from India, and *Wei Hei*, from China (Susi, Johannesson, & Backlund, 2007). These games, were created to make officers better planners in battles and they can date from four thousand years. Nowadays, through the development of game technology, these “simple” games evolved into extremely complex simulators. Here, it is provided a low-cost alternative to traditional[3] simulations. Also, these are recognized as a tool for training recruits with low literacy skills but high skills on game playing (Stewart & Misuraca, 2013).

For its training purposes, the United States (U.S.) Army was one of the first to show interest on gaming technology (Djaouti, Alvarez, Jessel, & Rampnoux, 2011). Designed and used for military training, *Army Battlezone* (Atari, 1980), Figure 2.2, was one of the first digital games used in simulations. This was possible because Atari adapted the original game, allowing the player to be capable of controlling a real tank.

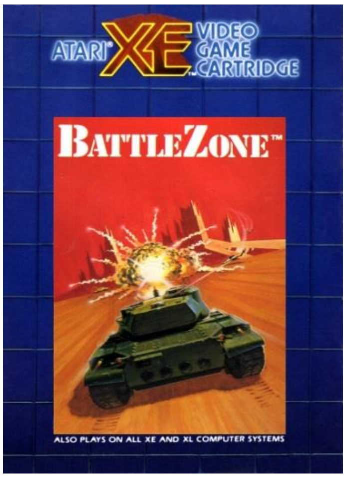


Figure 2.2 – *Army Battlezone* (Most Popular Video Games of all The Time, 2014).

One of the most well-known digital games, used with military purposes, is *America's Army*. This game was also developed for the U.S. Army and was released in 2002. It is free-of-charge over the internet and achieved over 17 million downloads in 2004 (Stewart & Misuraca, 2013). This platform was the solution encountered by the U.S. Army, in the late 1990s, on how to reach and recruit new volunteers. In that matter, this game was a success, helping recruiting soldiers at 15% of the cost of other programs (Susi, Johannesson, & Backlund, 2007). Also, according to (Grossman, 2005), about 30% of Americans between 16 and 24 years old have claimed to learn about the Army through this game.

Starting with board games to most recent digital games, many advantages have been brought by using serious games. Still, other skills, such as foreign languages and cultural training, are starting to receive some efforts by this area of application (Susi, Johannesson, & Backlund, 2007).

- **Educational Games**

Educational games is a category where most serious games could fit, for instance teaching how to operate a military tank or medical instruments. For that reason, it is stated that serious game can cross multiple areas. However, when considering just educational games, these tend to be referred as replacements to text books, classes and other media (Stewart & Misuraca, 2013).

Related to this area, "edutainment" was one of the first terms to appear, alongside computer games during the 1990s. Nevertheless, the interest on this concept decreased. According to (Susi, Johannesson, & Backlund, 2007) many reasons can explain this decrease on the interest, however two reasons stand out:

[3] Traditional simulations refer to combat training of real life situations.

- The (poor) quality of the games; and
- The growing interest in the Internet.

Nonetheless, as stated by (Stewart & Misuraca, 2013), “this is changing with new expertise, tools and changing business models for distribution”.

Many examples exist for this area. However, one of the first educational games to appear was *The Oregon Trail* (1971), illustrated in Figure 2.3. This text-only game was created by three History teachers and became one of the most famous ancestors of current serious games (Djaouti, Alvarez, Jessel, & Rampnoux, 2011). Providing an environment rich with information related to 1848 American history, the main goal consisted on the players trying to reach Oregon.

Figure 2.3 – The Oregon Trail (Most Popular Video Games of all The Time, 2014).

A more recent example of an educational serious game is *Genomics Digital Lab*. This game is focused on helping the player to understand cell biology and its importance in our lives (About, 2010). Thus, through simulations *Genomics Digital Lab* attracts and engages students. Also, among others, it promotes critical thinking, creativity and problem solving skills.

In contrast with schools, where discrete chunks of information are learned, the learning process in games consists on repetition and exploration (Ulicsak & Wright, 2010). This led these authors to conclude that “games are not an effective teaching tool for all students”. Nonetheless, current research is showing positive effects of serious games as educational tools (Susi, Johannesson, & Backlund, 2007). In fact, this type of games can support development of various skills, for example, planning, communication and collaboration. However, “hard” facts and evidences are still required to be demonstrated by researchers.

- **Healthcare Games**

The area that is becoming more common is related to Healthcare games (Susi, Johannesson, & Backlund, 2007). In fact, this area is expected to have the strongest growth within serious games (Stewart & Misuraca, 2013), (Susi, Johannesson, & Backlund, 2007). Currently, according to (Stewart & Misuraca, 2013), the available products are divided in four different aims:

- *Wellness*, where the games aim to assist in fitness or dieting;
- *Prevention of ill health*;
- *Rehabilitation*, which can overlap with *prevention of ill health*;
- And, *products for professionals*, simulators used for training of professional workers.

Among many other examples, *Captain Novolin*, illustrated in Figure 2.4, (Raya Systems, 1992) and *Packy & Marlon* (Raya Systems, 1994) are games that stand out on the area being designed to teach kids how to manage diabetes (Djaouti, Alvarez, Jessel, & Rampnoux, 2011). For instance, during the gameplay, the player needs to take into account the food that is eaten and the need to take insulin.

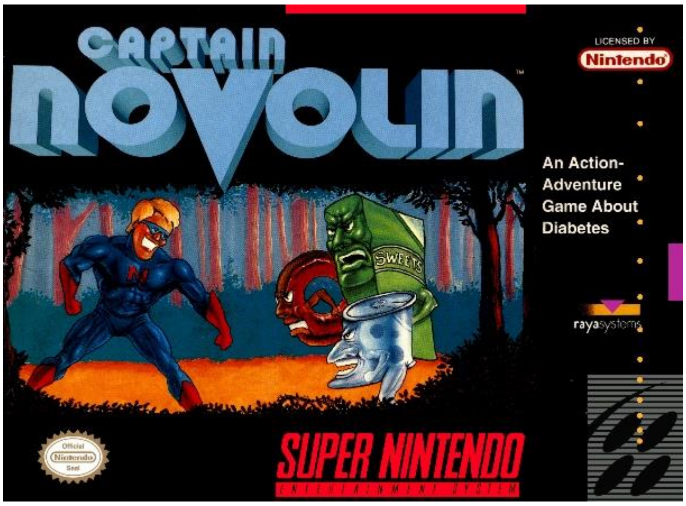


Figure 2.4 – *Captain Novolin* (Captain Novolin, 2014).

Being a game of medical interest, research studies were made to analyse the effect of these games on children. In fact, the study made on *Packy & Marlon* showed that after playing this game children were able to better manage their diabetes. Here, compared with other children, the number of glucose crisis, for the "players", decreased by 77% (Djaouti, Alvarez, Jessel, & Rampnoux, 2011).

This means that healthcare-related serious games "can have direct or indirect positive physiological and psychological effects on individuals" (Susi, Johannesson, & Backlund, 2007).

2.1.3 Serious Games for Language Learning

"The evolution of technology and the strong belief that computer games promote learning, have contributed to the increase of educational computer games available online in the field of teaching and learning a foreign language" (Krystalli, Arvanitis, & Panagiotidis). Nonetheless, language learning has been moving away from the (common) grammatical based learning into a communicative based learning, thus, changing the main format of the learning approach to: task-based, project-based and content-based (Sorensen & Meyer, 2007).

In fact, serious games do not purposely provide all the resources required to learn a language. Instead, they teach common vocabulary for situations where they can be useful (Silva, Mamede, Ferreira, Baptista, & Fernandes, 2011), one example being *Polyglot Cubed*. Still, serious games intended to explore vocabulary do exist. The best example is *Mingoville*. This game is composed of 10 different themes (e.g. Family, Body, etc.) and is used for teaching English (Sorensen & Meyer, 2007).

Other examples where serious games can be used for language learning are the serious game applied to sign language – the target of this research work. After some research, it has been found that the variety is scarce.

In fact, most of the discovered serious games are based on the game Bingo[4]. Three examples of those games are shown below (see Figure 2.5):

- *Sign Language Bingo*, a board game with 201 basic sign vocabulary words (Winnie & Drennan, 2008).
- *Sign-O*, a computer game, also based on bingo, with 12 themes and boards containing 25 words (Sign-O, 2007).
- *Sign the Alphabet*, an online game that is played by identifying the letters and numbers that are shown (Sign the Alphabet, 2011).

(a) *Sign Language Bingo* (b) *Sign-O* (c) *Sign the Alphabet*

Figure 2.5 – Example of games available for teaching Sign Language

Despite most games are based on *Bingo*, they can be useful for teaching sign language. Nonetheless, this creates a gap where, on one hand, this sort of games can be based on other games and there is the possibility, through the usage of NUIs, to create an interactive serious game capable of recognizing and evaluating sign language.

2.2 Natural User Interfaces

Natural User Interfaces are the devices that allow a more user-friendly experience when controlling hardware devices of software applications (User Interface, 2009). These devices are designed to make an interaction to feel as natural as possible to the user (NUI, 2012). For instance, touchscreens are one of those interfaces, which provide a more natural usage when compared with the keyboard and the mouse.

The purpose of this section is to study natural user interfaces and, in particular, sign language recognition (SLR) systems. For that reason, the concept of NUI is clarified and some related concepts are explained. Furthermore, a study of the actors in the market is done, by presenting some variety of products that allow SLR. To conclude the section, some examples of SLR systems are presented.

2.2.1 History and Usage of Natural User Interfaces

“Human computer interaction have become an everyday occurrence, and over the last few years the term natural interfaces has emerged” (Jensen, 2011). In fact, the field of NUI has suffered a boom, in the most recent years. The improvement of old technology, such as the creation of new touchscreens, and the development of new ways of using old sensors, such as gyroscopes, are the main causes for this boom.

[4] “Bingo is a game of chance played with randomly drawn numbers which players match against numbers that have been pre-printed on 5×5 matrices” (Bingo, 2014). For the Bingo-based sign language games, instead of numbers, sign are randomly picked and must be reproduced to identify that the player has that sign.

Contrary to common knowledge, interfaces exist for a long time (Revolutionary User Interfaces, 2013). *Antikythera*, which only provided outputs, is one early example of a mechanical computer and it was used to track the cycles of the solar system. Many years later, in 1642, Blaise Pascal invented a calculator that could add and subtract in one step or multiply and divide by repetition. In this case, small spinning wheels were used as inputs. However, since then, interfaces have changed considerably, for example the appearance of the keyboard in 1870 and the mouse in 1968. Nonetheless, the biggest change was the appearance of the monitor in 1964 and with it the predecessor to graphical user interfaces (GUIs) (Graphical user interface, 2014). NUIs came in 1997, when the first touchscreen appeared in the commercial product called *The Stylus*. This product offered handwriting recognition, but still in a "hit or miss" way (Revolutionary User Interfaces, 2013).

Much has been achieved in the field of interfaces, most in the recent years for the NUIs, as illustrated in Figure 2.6. For that reason, this concept was defined as a user-friendly interface that comprehends a human-machine interaction that is as natural as possible for the user (NUI, 2012). Nevertheless, according to (Broy & Rümelin, 2012), this form of human-machine interaction can be split in two different modalities:

- The input modality where the person uses speech, touch or gestures to provide information;
- Or the output modality where the person receives auditory, haptic and visual feedback.

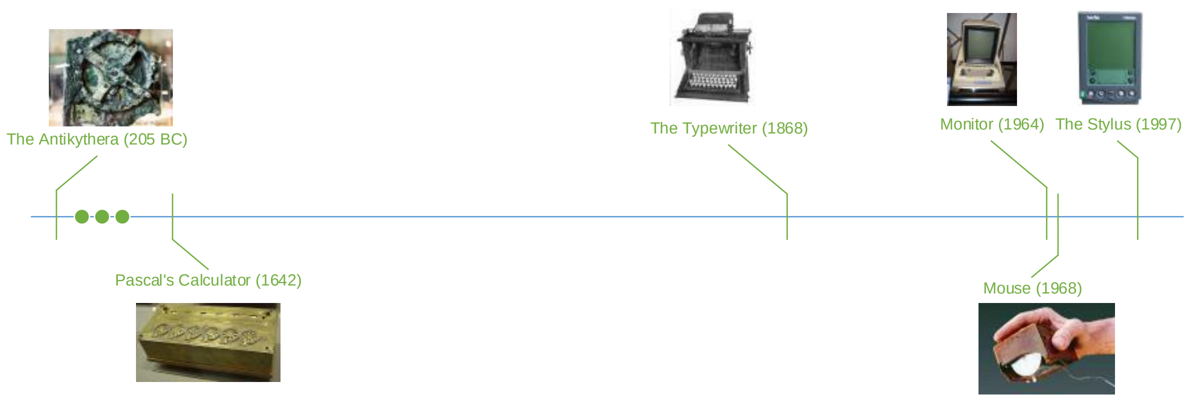


Figure 2.6 –Timeline of Interfaces

2.2.2 Actors in the NUI Market

Starting from touchscreens, currently, NUIs have evolved into sensors capable of recognizing human movements and sounds. An example of such sensors is the *Kinect Sensor*, created by Microsoft, which is capable of detecting and recognizing the human skeleton, speech and many other features. After Microsoft turned this futuristic dream into reality, other devices started appearing and making competition with the *Kinect Sensor*. From those, two devicescan be highlighted:

- *The Leap* by Leap Motion, publicly announced on May 21, 2012 (Leap Motion, 2013), was designed to work on a physical desktop facing upwards. This device was idealized for finger tracking, in which fingers hover over the device;
- Produced by Intel, the second device is *Intel's Interactive Gesture Camera* (IIGC), and, being built in a cheaper and smaller format, was intended to provide the same features as the *Kinect Sensor* (Intel Software, 2013).

Erro! Autorreferência de marcador inválida. provides an overview on the characteristics of these devices. From this overview, we conclude that each device is specialized in different features. For instance, the *Kinect Sensor* is better suited in situations where the user stands away from the display. The second device, *The Leap*, is more appropriate when using pointing base UIs. Finally, the IIGC is better suited for users that are seated in front of the computer.

Table 2.1 – Pros and Cons from the three devices studied (Depth Sensor Shootout: Kinect, Leap, and Intel, 2013)

Device	**Pros**	**Cons**
Kinect Sensor	• Applications can track the user position in space, through the skeleton tracking. • Various attributes of the user face can be tracked. • Multiple sensors can be used together. • Kinect SDK turns available the raw data from the sensors. • The microphone array is capable of tracking the user voice in order to better capture speech.	• Fairly large in comparison with other devices. • There is a need of a dedicated power cord. • The resolution for the depth sensor is not as good as other devices in the market. • Only two players can be tracked in detail, when it's possible to detect six players. • Kinect SDK is only available for Windows 7 and 8.
The Leap	• The finger tracking is fast and accurate. • The hardware is very small and inexpensive. • There is an application store that provides a way to share Leap apps. • This device supports a large number of frameworks. • Works both on Mac OS and Windows.	• The sensing range is very limited, up to 1 meter. • Only tracks fingers, there is no skeleton or face tracking. • The raw data is not available.
Intel Interactive Gesture Camera	• It's smaller and less expensive than the Kinect for Windows sensor. • Specially built for close-range tracking. • Hand postures and gestures can be recognized through the SDK. • Provides capabilities for facial tracking and analysis. • Speech recognition can be predefined and the SDK provides a built-in support for speech synthesis. • Developers have access to raw data from the sensors • It can support frameworks like Processing, Unity and Open Frameworks.	• Trying to obtain some of the deeper features can get a bit tricky. • The hand gestures, when designing, must not obstruct the face of the user.

2.2.3 Sign Language Recognition Systems

Sign Language Recognition (SLR) has been of great interest to the computer vision and image processing research community for the past 20 years, an example is the work of Starner (1995). This interest has derived from the characteristics of sign language and its importance in the lives of deaf people. However, the improvements made on SLR were very limited and only provided initial approaches to SLR, being limited to the number of recognized signs.

For that reason, the researches being made on this field were scarse. However, with the appearance of the *Kinect Sensor* a change on that interest has occurred. This was possible due to the development of the depth camera that exists in the *Kinect Sensor*. Furthermore, another topic that assisted in the SLR field was the evolution on machine learning and computer vision.

Machine learning algorithms have been used from the start in SLR, for instance the utilization of Hidden Markov Models by Starner (1995). However, they were based on statistical models and used with the assistance of solid colour gloves for determining good results. Starner achieved 97% accuracy with a forty word lexicon (Starner, 1995).

More recently, Correia (2013) proposed two different algorithms for SLR: 1 – a K-Nearest Neighbour (KNN); and 2 – a Support Vector Machine (SVM) (Correia, 2013). Just like in Starner' work (1995), Correia (2013) was able to achieve good accuracy results, 96.58% for the KNN and 92.06% for the SVM. However, this study only included four letters of the sign language alphabet.

One of the most recent studies was made from the cooperation between Key Lab of Intelligent Information Processing, from China, and Microsoft. On this study, three dimensional trajectories of the sign are used on matching signs. By using the Kinect sensor, the trajectory of the user hand is acquired and after, normalizing its trajectory, linear resampling, and comparing with the trajectories gallery, better results can be obtained. This presented study achieved 96.32% accuracy for a gallery with 239 signs (Chai, et al., 2013).

2.3 Summary

According to the conducted study on the fields of interest, it was verified that numerous definitions for the “serious game” concept do exist. However, the definition that states a serious game as a game used with a serious purpose, is deemed has the most accurate one. Also, there are multiple areas (e.g. military, healthcare and education) where this sort of games have been applied. For instance, serious games can be applied to the teaching of sign language. But in this regard, there is little diversity in the existing games, as mentioned in section 2.1.

The other subject studied on this chapter is NUIs. This field is concerned with interfaces that provides a more natural human-machine interaction. Therefore, the comparison on some market products was conducted, providing some pros and cons for each existing solution.

To conclude, a deeper study was conducted on SLR systems. From this study it was concluded that most systems achieve high accuracy rates but are limited on the amount of recognizable signs.

3. Proposal

This research work proposes a system devoted to support the teaching of (Portuguese) sign language, to non-deaf, through the use of serious games. According to the state of the art described in chapter 2, it was verified that the teaching of sign language is made, nowadays, from rudimentary serious games that do not support any SLR system. As a result, this aspect (the SLR) is also included in the current proposal.

This chapter describes the modelling of the proposed solution and highlights some aspects on how it might be implemented, for validation purposes. Thus, the modelling will be composed of the main entry points of the system throught use case diagrams, the system architecture and the system behaviour.

3.1 "Entry Points" Modelling

In order to define the functioning of the solution, a model of it is now described. Then, the following points state the objectives the implementation must achieve:

- The user must spell sign language in order for the game to proceed;
- Considered that the prototype is a game, a graphical interface must be constructed; and,
- Being non-deaf people the target of the proposal, then other engaging features must be added to the prototype.

Therefore, considering all these objectives, the user interaction with the proposed solution, must comprise the functions that are illustrated in the Use Case Diagram of Figure 3.1.

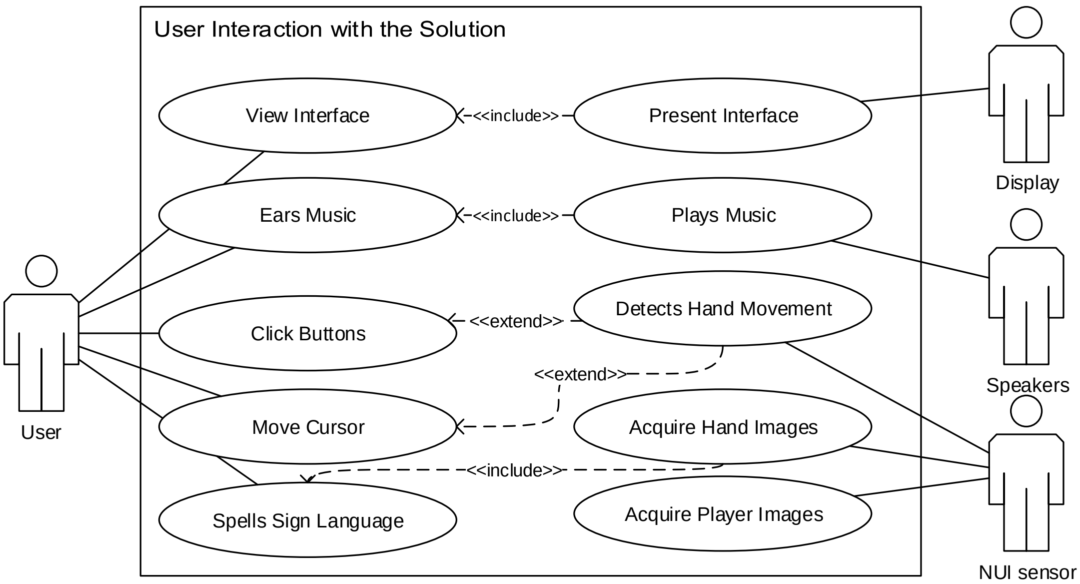


Figure 3.1 – Use Case Diagram of the user interaction with the Prototype

Now, that the interaction with the solution is defined, it is necessary to define how the actual prototype will function. According to Figure 3.1, the following requirements are then needed:

- Detection/acquisition of information provided by the user, where this information is responsible for the workflow in the solution;
- Definition of the information provided to the user; and,
- Definition of the multiple stages of the game, since the user is not continuously playing or learning.

Then, according to these requirements, it is clear that there is a need to create a module capable of collecting and processing data. Since this solution requires the recognition of sign language, a distinct module should take this responsibility. Finally, there is also the need to implement a module capable of controlling the stages of the game and to provide feedback of these changes to the user.

Only the most important stages must be visible. Therefore, two main stages where the user transits between them are defined. These stages are called “Play” and “Navigation”, according to the moments when the user is playing the game or navigating through the menus. Also, considering that the user can play or learn with sign language, due to the definition of serious game, two modes of play are created: the *School-mode* and the *Competition-mode*. Combining these stages, the use cases, visible to the user, are presented on Figure 3.2.

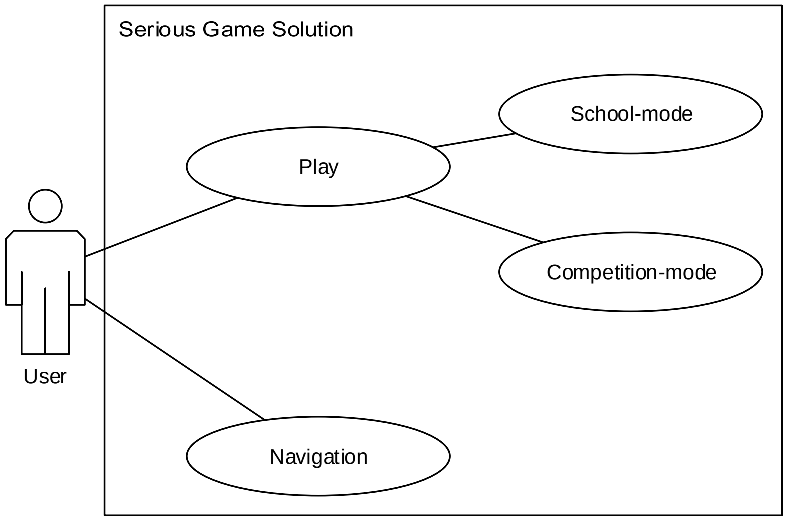


Figure 3.2 – Use Case Diagram for the stages visible to the User

3.2 Architecture

With the modelling completed, it is time to create a corresponding architecture. Therefore, the resulting architecture, shown in Figure 3.3, consists of three main components:

1. The interfaces, shown in blue, representing the inputs (e.g. NUI sensor) and outputs (e.g. display) of the solution;
2. The knowledge base (KB), responsible for storing all relevant information (e.g. SL recognition information); and
3. Three relevant modules, used to process the information according to the flow of the game.

These modules, present on the mentioned Figure 3.3 are:

- The *Game Module*, which is responsible for controlling not just the outputs but also how the other modules function, during gameplay;
- The *SLR Module*, which has the responsibility to recognize sign language;

- The *Data Acquisition (DA) Module*. This module was created to receive the information from the inputs and correctly channel it to the other modules.

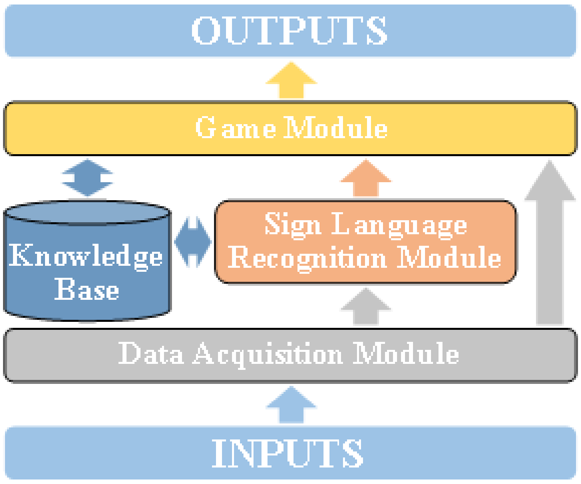


Figure 3.3 – Prototype architecture

A more detailed explanation of these modules is presented in the following sections. Also, according to the flow of information in the solution, a bottom-up approach will be taken into consideration. Therefore, the first module to be explained is the *DA Module*, followed by the *SLR Module* and, to conclude, the *Game Module* is detailed.

3.2.1 *Data Acquisition Module*

The first developed module is the *DA Module*. This module is responsible for the data acquisition, with either a NUI sensor or not. This possibility allows the usage of the prototype not just by any player, but also eases the implementation process. Thus, as visible in Figure 3.4, there are two forms of inputs: 1 – the NUI sensor; and 2 – the computer keyboard and mouse.

Figure 3.4 is a representation of the dataflow inside the *DA Module*. Here, the data acquired from the computer keyboard and mouse is passed directly to the *Game Module*, while the data acquired with the NUI sensor is filtered and then passed, accordingly with the block that is expected to receive the information in the subsequent module.

There are three blocks to process the NUI sensor data, as shown in Figure 3.4:

- The first block is the "Hand Image" and it is designed with two objectives: the first is to convert the raw depth data of the hand into a standard format, and by doing so, it allows the recognition of a sign in the *SLR Module*; the second objective is to get the RGB equivalent image of the hand acquired from the raw data and send it to the *Game Module*, in order to display it to the user.
- The second constructed block is the "Green Screen". This is a relatively simple block with just he role of acquiring a green screen-like image of the player, in order to create the effect of Figure 4.4 during the play of the *Lingo*[5] game.

[5] *Lingo* is a derivation of *Bingo* and was first presented on an American television game show. "The show's format combined the structure of the game of chance known as bingo with a word guessing game", (Lingo (U.S. game show), 2013). The game objective is to find the correct five letter word in five tries.

- The last block, “Hand Position”, is intended to detect the position of the hand and, through a conversion of this position, places the cursor on a new position. In other words, the cursor moves accordingly to the players’ hand.

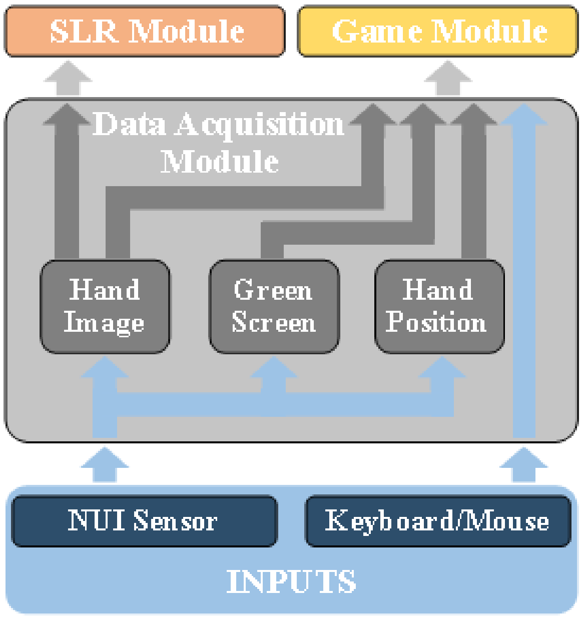


Figure 3.4 – Architecture of the *Data Acquisition Module*

3.2.2 *Sign Language Recognition Module*

This module is responsible for the recognition of sign language. According to chapter 2.2.3, SLR is a subject of great interest for the computer vision and image processing scientific community and there are various possible solutions for the SLR problem. However, being a first approach on teaching sign language through serious games, it is proposed a simple recognition algorithm, as a support to this approach.

For the recognition algorithm, the objective will be the ability to identify the sign language alphabet. In other words, it will only detect signs from static images. This means that for each image that is received, from the *DA Module*, the recognition algorithm must match it with the images in the *Knowledge Base* and, if the match is above a certain threshold, the *Game Module* is notified about the recognition of an existing sign.Contrary to the other modules, this has only one responsibility, recognizing signs from images. Therefore, the architecture is very simple, as illustrated on Figure 3.5.

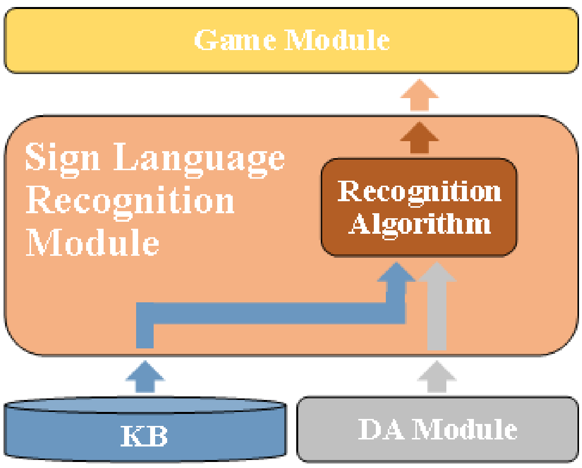


Figure 3.5 – Architecture of the *Sign Language Recognition Module*

3.2.3 *Game Module*

The last implemented module is the *Game Module*. This module is developed in order to allow the user to play/learn with the serious game. In order to achieve these objectives, the solution is divided into two main modes:

- The first mode is the *School-mode*, which concerns the teaching of the sign language alphabet;
- The second mode, called *Competition-mode*, is responsible for making the player apply the knowledge obtained into two mini games, *Quiz* and *Lingo*.

According to the architecture shown in Figure 3.6, this module receives data from the *SLR* and *DA Modules*, exchanges information with the *Knowledge Base* and provides information to the *Outputs* (speakers and display). Inside the module itself, there are four blocks:

1. The “Sound & Music” block, which is responsible for the reproduction of environment music and action sounds (e.g. the clicking of a button produces a sound);
2. The “Play” block, used when the user is playing a lesson/game, according to the modes of play;
3. The “Navigation” block, used to navigate between pages, modes and menus; and
4. The “Interface” block, that is responsible for providing the necessary information through the display.

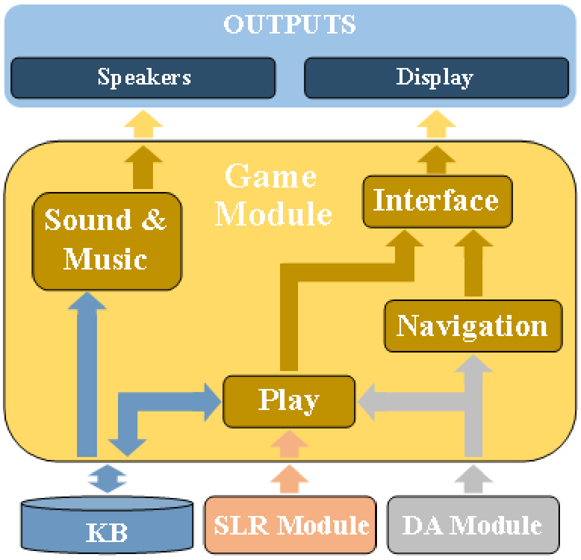


Figure 3.6 – Architecture of the *Game Module*

3.3 System Behaviour Modelling

To conclude, the behaviour of this system is also modelled. According to the proposed architecture, the general behaviour, visible on the sequence diagram of Figure 3.7, is similar among the modules. In other words, it means that each block receives information, treats it accordingly and sends the new information to the following block.

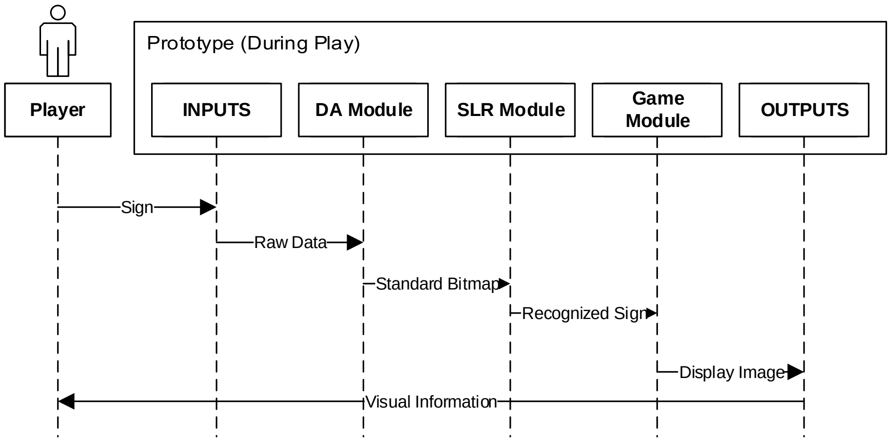


Figure 3.7 – Sequence Diagram of the General Flow of Information during Gameplay

Nonetheless, the behaviour of the *SLR Module* is different. As shown in Figure 3.8, the difference resides in the loop cicle responsible for comparing all the *KB* images with the new image, in order to provide the recognized sign into the *Game Module*.

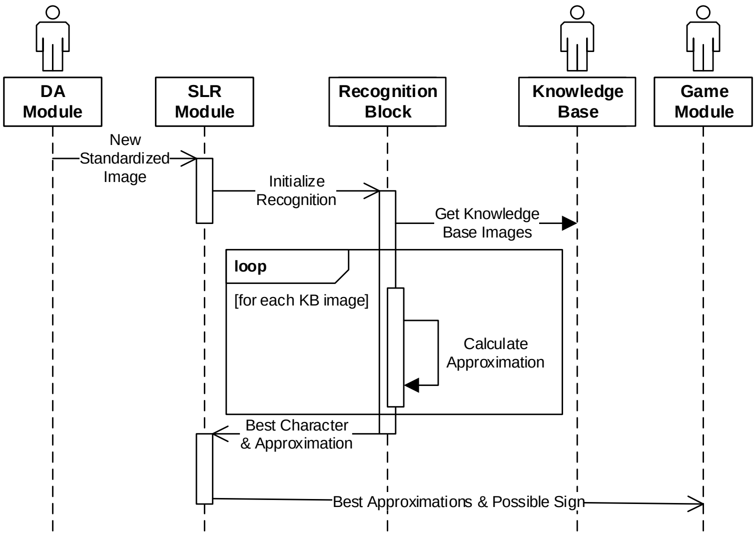


Figure 3.8 – Sequence Diagram for the Recognition of a Sign

3.4 Summary

In order to conduct a study on the utilization of serious games to teach sign language, a model of a serious game is proposed. This model allows the player to learn and play with (Portuguese) sign language alphabet. According to these features, some “entry points” modelling are then devised. With those points and a few use case diagrams, the main functionalities of a proposed serious game is presented.

After this “entry points”, a possible architecture is presented. In this architecture, interfaces (for input and output), a knowledge base and three modules are proposed. In particular, the modules are intended to allow the standardization of the acquired data (*DA Module*), recognition of sign language (*SLR Module*) and process the acquired information into the serious game itself (*Game Module*).

For last, the behaviour of the proposed system is modelled. In order to model this system, sequence diagrams are presented and, they serve to visualize that most of the proposed system behaves linearly, passing information from a previous module/source into the next module/source. Appart from this behaviour, the *SLR Module* is presented in more detail due to the required recognition process.

4. Implementation

In order to implement the architecture presented on Figure 3.3, first, adequate development tools need to be selected. Therefore, this chapter begins with a section about the required tools, for instance presenting the selected NUI sensor. Also, according to the same architecture, the implementation of the prototype is discussed. Thus, all implemented modules (*DA Module*, *SLR Module* and *Game Module*) will be described in great detail, where all relevant information is presented, such as mathematical functions, portions of code and examples.

4.1 Development Tools and Resources

The prototype, used on the study of the proposal requires certain tools to assist in its development and usage. Therefore, this section is dedicated to the description of the necessary tools used on all the modules of the prototype:

- The first selected resource is the NUI sensor, since the selection of this resource will influence the selection of other tools;
- The following tool is the Integrated Development Environment[6] (IDE), which must be capable of supporting the implementation of the prototype according to the sensor;
- The last selected tool is an image processing library. This library is necessary for the standardization of the information that is used during the recognition process.

In terms of selected tools, it was selected the *Microsoft Kinect Sensor*, as the NUI sensor. Then, the selected IDE is *Microsoft Visual Studio*. In terms of image processing library the *Emgu CV* wrapper was selected. The reason for selecting a wrapper, instead of the actual library, is based in the fact that the wrapper uses the C# language, which is the language used on the implementation of the prototype.

Prior to the implementation of the desired serious game, the functionalities of each tool are shown in greater detail. For that reason, the following sections provide an introduction about the capabilities / features of those tools.

4.1.1 Microsoft Kinect Sensor

The selected NUI should provide features capable of assisting in the development of the *SLR Module*. For that reason, and according to Erro! Autorreferência **de marcador inválida.** provides an overview on the characteristics of these devices. From this overview, we conclude that each device is specialized in different features. For instance, the *Kinect Sensor* is better suited in situations where the user stands away from the display. The second device, *The Leap*, is more appropriate when using pointing base UIs. Finally, the IIGC is better suited for users that are seated in front of the computer.

[6] An integrated development environment (IDE) is a software application, normally consisting of source code editor, build automation tools and debugger, which facilitate software development by computer programmers (Integrated development environment, 2014).

Table 2.1, the *Kinect Sensor* was chosen. This sensor was one of the first to alienate the standard UIs (e.g. mouse). Instead, through this sensor, the natural movements of the body can be used to control the form in which the game is played.

This new form of control is possible due to the introduction of the third dimension on the computer vision field. This dimension, expressed as distances from the sensor, rely on the “eco” of infrared lights or, in other words, it measures the distortions between distinct infrared beams, sent by the sensor.

According to Figure 4.1, the Kinect sensor is composed of the following elements:

1. The *depth camera*, or infrared optics, responsible for understanding the 3D environment in front of the Kinect sensor;
2. The *RGB camera*, which besides showing the user on screen it is also responsible to make the facial recognition of the user;
3. The *motorized tilt*, mechanical gear that let the sensor follow the user;
4. The *multi-array microphone*, composed of four microphones embedded inside the Kinect sensor, is capable of isolating the user voice from the rest of the noise. It is also capable of pinpointing the user location correlated to the Kinect sensor.

Figure 4.1 – Composition of the Kinect sensor: (1) – Infrared optics; (2) – RGB camera; (3) – Motorized tilt; (4) – Multi-array microphone

Responsible for identifying the information acquired by the infrared optics, the *Kinect Sensor* possesses its own *processor* and *firmware*. It is from those that extrapolating two human skeletons, composed of more than 20 joints, is possible (Kinect, 2013). Also, another provided feature used for the selection of this sensor is the existing Software Development Kit, created by Microsoft.

4.1.2 Microsoft Visual Studio

In order to develop the proposed prototype an IDE is required. For that reason and because the *Kinect Sensor* is used, the development of the prototype is made on *Microsoft Visual Studio*. Through this IDE, it is possible to develop multiple types of applications. Nonetheless, for the current implementation WPF[7] is selected.

Another reason for selecting this tool is that *Visual Studio* is one of the most complete IDEs for software development, offering a great variety of features. Some of these are the integrated debugger, which works both as a source-level and as a machine-level debugger, the forms designer, for building graphical interfaces on the applications, and the IntelliSense, which allows the completion of code (Microsoft Visual Studio, 2014).

[7] Windows Presentation Foundation (WPF) is a graphical subsystem for rendering user interfaces in Windows-based applications (Windows Presentation Foundation, 2014).

By selecting *Microsoft Visual Studio*, the type of application where the prototype is developed must support all the features proposed on section 3.2. Also, the selection of this IDE, instead of a game engine, is justified with the familiarity with the software development procedures and the complexity of the architecture is suitable to these tools.

4.1.3 Emgu CV

The last required tool, for the development of the prototype, is the image processing library. The selected library is *Open CV*. However, because this library is not written in C#, it is not supported for the development of the prototype. Instead, a cross platform wrapper for this library is used. This wrapper is called *Emgu CV* and allows the utilization of *Open CV* functions in the .NET Framework (Main Page, 2013).

The features that make this library useful for image processing is the fact that it takes advantage of multi-core processors and is able to turn image processing into real-time (Costa, 2013). Also, other important feature are the more than 350 computer vision algorithms, existent in this wrapper (OpenCV, 2010).

4.2 *Data Acquisition Module*

After selecting the proper tools to be used on the implementation, the first module, the *DA Module*, is implemented. This module has the responsibility of acquiring data and treating it properly, whether the player uses a NUI sensor or the computer keyboard and mouse. However, when working with the NUI sensor, the module must also conduct other works, such as determining the hand position correlated to the display.

Just like the *Game Module*, this module will operate according to the two gameplay modes. Therefore, the description of this module implementation is divided into those two modes.

4.2.1 *Navigation-mode*

The first mode of play is the *Navigation-mode*. In order to support this mode, the prototype uses the "Hand Position" block to detect the right hand of the user and convert that position into screen coordinates. In other words, this makes the user hand equivalent to the computer mouse.

Nevertheless, a problem was found when implementing this system. How to simulate the clicking on an interface button? To solve this problem, a counter was added to the block, where if the user hand stays over a button for more than 5 seconds, then it means that the user wants to click on that button.

As illustrated in Figure 4.2, there's an example of using this mode. This is when a guest user selects its own gender in order to play the game. In this case, the user clicks on the gender by using the mouse or, when using the NUI sensor, by placing the cursor over the gender and waiting 5 seconds.

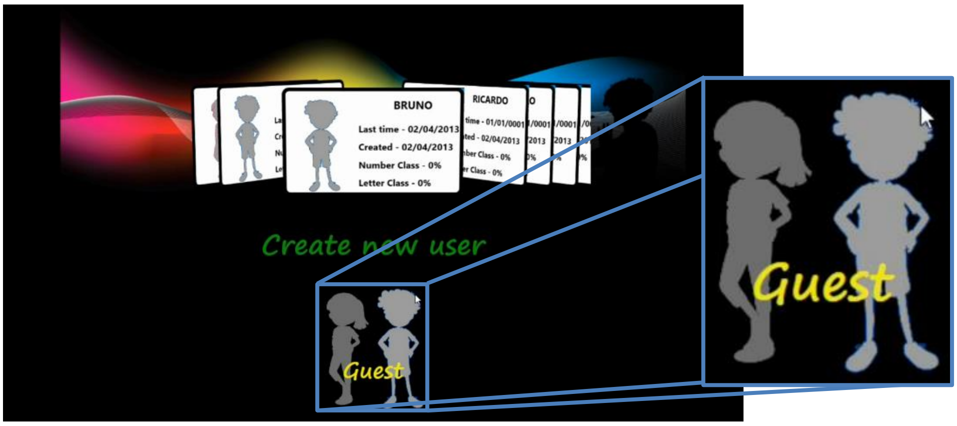


Figure 4.2 – Example of usage for the *Navigation-mode*

4.2.2 *Play-mode*

For the other mode, the *Play-mode*, the inputs are used with different purposes. On one hand, the NUI sensor is used on multiple features of the game, such as SLR or image feedback (Figure 4.3), while, on the other hand, the mouse and keyboard are implemented to support the most common features, in other words, replace the SLR Module.

In what concerns the mouse and keyboard, they are used on different situations. The first was implemented to support the lessons and the *Quiz* game, while the second is used on the *Lingo* game. Nonetheless, it is through the use of the NUI sensor that sign language can be recognized.

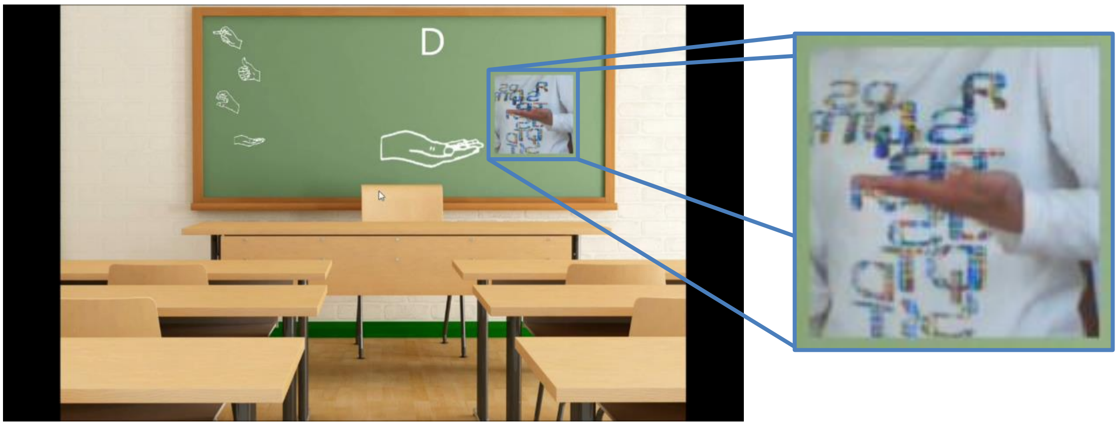


Figure 4.3 – Usage of the “Real Hand Image” filter during *Play-mode*

During this gameplay mode, only the “Hand Image” and the “Green Screen” blocks are used, each having the responsibility of providing different information. On one hand, the “Green Screen” block is responsible for creating a green screen-like image of the user, just like on Figure 4.4. On the other hand, the “Hand Image” block is responsible for providing the image highlighted on Figure 4.3, and also to provide a standard image to be recognized by the *SLR Module*.

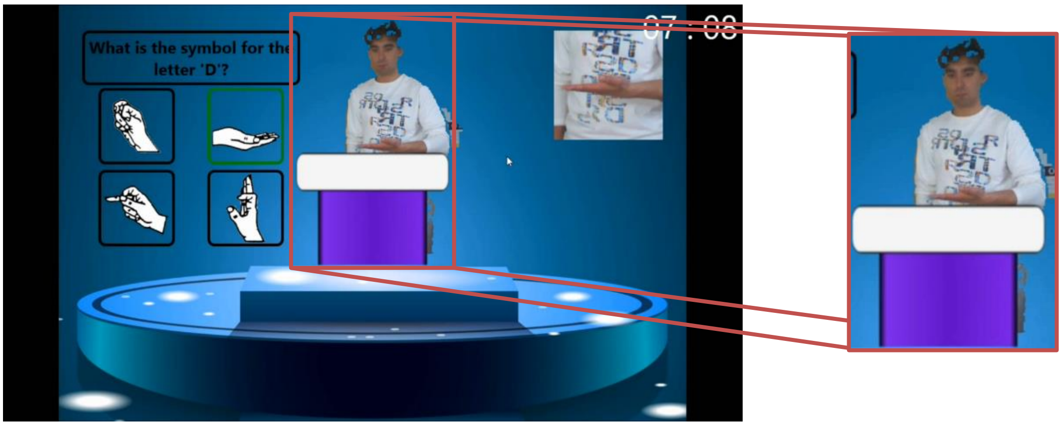


Figure 4.4 – Usage of the “Green Screen” filter during Play-mode

Since the image provided to the *SLR Module* is a standard 144×144 grayscale bitmap, a process of standardizing that raw data must be followed. Therefore, such raw data must go through the following four steps:

1. Obtain the user right hand position.

With the assistance of the NUI sensor, and the provided SDK, the user right hand position must be determined. Since the SDK already provides the skeleton of the user, the position of the user right hand can be obtained by using Code 4.1.

Code 4.1 – Code to obtain the user right hand position

```
SkeletonPoint sr = this._skeleton.Joints[ JointType.HandRight ].Position;

CoordinateMapper mapper = this._kinect.CoordinateMapper;
ColorImagePoint cr = mapper.MapSkeletonPointToColorPoint( sr, currentColorImageFormat );
```

According to Code 4.1, the right hand position is obtained, with the assistance of the SDKon the first line of code. The position result is three dimensional, as illustrated in Figure 4.5, and refers only to the joint of the skeleton. This means that if this point is used directly on the colour or depth frame, it can be different from the actual hand location.

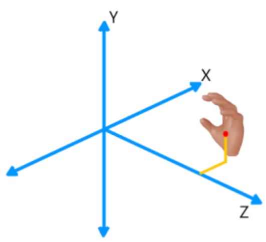


Figure 4.5 – User right hand position

Therefore, a class called CoordinateMapper is used, which allows the conversion of points from different sources of the sensor. On the example, Code 4.1, the skeleton point is converted into a colour point, inside the colour frame, which doesn't invalidate the possibility of converting the skeleton point into a depth point.

2. Determine the hand region of interest (ROI).

After determining the right hand position, it is necessary to determine a ROI where the users hand is most likely to be, Figure 4.6.

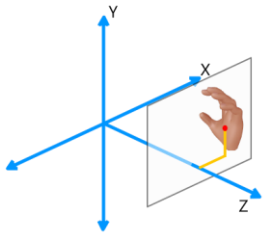


Figure 4.6 – ROI covering the entire user right hand

To obtain this ROI first it is necessary to determine the size of the image that is acquired. Therefore, according to the distance of the user to the Kinect sensor (z), the ROI must differ in dimension, where the farther away the user is from the sensor the smaller the image size is. Taking this into consideration, Equation 4.1 was obtained to determine the size of the image.

Equation 4.1

$$GetSize(z) = MaxROI - (DepthToPixel * z)$$

This Equation 4.1 states that the ROI size is the difference between a maximum size ($MaxROI$) and the multiplication of a depth to pixel conversion constant ($DepthToPixel$) with the distance of the user hand to the sensor (z).

Code 4.2 – Portion of the code to determine the ROI

```
int size = this.basic.GetSize( sr.Z );
ColorImagePoint[] crCorners = this.basic.FindBoxCorners( cr, size );
```

Code 4.2 shows the usage of Equation 4.1 (function GetSize). After determining the ROI size, the corners of this ROI are determined. These corners are determined so that it can be possible to later split the ROI from the entire image.

3. Translate the depths of the raw data into grayscale.

After determining the region of interest, the first process on standardizing the image is to convert the raw depth data into grayscale. Nevertheless, a condition must be met in order to convert the depths into grayscale: the desired depth must be inside a depth threshold, as illustrated in Figure 4.7.

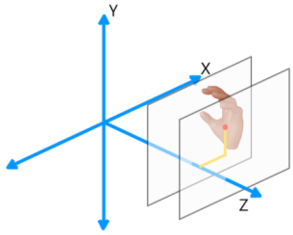


Figure 4.7 – Threshold example according to the ROI

Equation 4.2 shows the formula that is used to convert the depth into greyscale. It states that only the depth points inside a threshold are converted to grey, while any other points, outside the threshold, are placed without colour.

Equation 4.2

$$Gray_i(Depth_i) = \begin{cases} \dfrac{(Depth_i + HV - z) \times 255}{2 \times HV} & z - HV < Depth_i < z + HV \\ 0 & otherwise \end{cases}$$

Inside the hand threshold, the depths are converted from 0 to 255. Here, if the depth is closer to the NUI sensor, the image turns black or if it gets away, from it, the image turns white.

When converting Equation 4.2 into code, the result is Code 4.3 where all the image pixels are converted from depth into a grey colour, in the case of being inside the threshold.

Code 4.3 –Code to convert the depth image into grayscale

```
// Obtain the depth at the center point
int centerDepth = DepthPoints[ ( Center.X + ( Center.Y * this.currentColorWidth )) ].Depth;

// Convert depth image to color image
for ( int i = 0; i < DepthPoints.Length; i++ ) {
    // Get current depth
    int depth = DepthPoints[i].Depth;

    // Verify if the depth is within the depth variation
    if ( (centerDepth - Constants.HandVariance) <= depth &&
                depth <= (centerDepth + Constants.HandVariance) ){
        // When the depth is within give that pixel a certain intensity in gray scale
        byte intensity = (byte)(( (depth + Constants.HandVariance - centerDepth) * 255 ) /
                ( 2 * Constants.HandVariance ));

        colorPixels[colorPixelIndex++] = intensity;
        colorPixels[colorPixelIndex++] = intensity;
        colorPixels[colorPixelIndex++] = intensity;
    } else {
        // Otherwise set the pixel to black
        colorPixels[colorPixelIndex++] = 0;
        colorPixels[colorPixelIndex++] = 0;
        colorPixels[colorPixelIndex++] = 0;
    }

    // Alfa component of the pixel (to be ignored)
    ++colorPixelIndex;
}
```

4. Split and scale the resulting bitmap into the 144×144 size.

After converting the depths into the greyscale, the resulting image is split and scaled into the size 144×144. In order to conduct this split and scale, the image processing library is used, since it provides the necessary functions optimized for image processing.

Code 4.4 – Code to split and scale the final bitmap

```
try {
    // Initialize image to be manipulated
    Image<Bgra, Byte> image = new Image<Bgra, byte>(Width, Height, new Bgra(0, 0, 0, 0));
    image.Bytes = Pixels;

    // Set region of interest
    image.ROI = new Rectangle(TopLeft[0], TopLeft[1], BottomRight[0] - TopLeft[0], BottomRight[1] -
TopLeft[1]);

    // Get region of interest, resized, to a new image
    Image<Bgra, Byte> newImage = image.Copy().Resize(Constants.FinalSize, Constants.FinalSize,
INTER.CV_INTER_NN);

    // Return byte array
    return newImage.Bytes;
} catch (CvException) {
    return null;
}
```

Using the *Emgu CV* library, these functionalities are implemented inside the function shown in Code 4.4. Here, through the use of a nearest neighbour interpolation, the splitting and the resizing of the ROI are described,thus creating the new image used on the recognition process.

4.3 *Sign Language Recognition Module*

As previously mentioned in chapter 3, this module is responsible for the recognition of the sign language alphabet from the standardized image. Therefore, in the implementation of this module, it is necessary to implement an image matching algorithm. This algorithm is designed with the objective of sending to the *Game Module* the recognized letter and the approximation of the match. Nonetheless, prior to the implementation of this module, two terms must be clarified:

- Approximation, which refers to the percentage of pixels that have similar values in two images;
- Accuracy, refers to the accuracy, in percentage, of the matches made by the algorithm.

This algorithm is explained in the following sections, including some problems faced and eventual solutions to those problems. Also, the implementation of this module, in order to be inserted into the serious game prototype, is explained.

4.3.1 SLR Algorithm

The module works when it receives a standard image from the *DA Module*. That image is then matched with the constructed knowledge base and, according to the results of this match, the module sends the recognized letter and the best approximation value, to the match in the knowledge base.

The algorithm was designed to be as simple as possible. Thus, it is constructed based on a pixel by pixel comparison. Here, the image received from the *DA Module* is matched with the images from the entire knowledge base. However, during this implementation two problems were detected:

- Since the pixel value can vary between 0 and 255, an exact comparison between images might not be the best algorithm possible. For that reason, a threshold, according to Equation 4.3, is added to the matching solution.

Equation 4.3

$$|DB_i - I_i| < V_d$$

- Also, if the matching comprehends the full extent of the image, the approximation between images will return high values, since the images are mostly black displayed as illustrated in Figure 4.8, it will make the recognition process more costly in terms of time. In order to solve this problem, five forms of image matching were devised. These forms are called filters and each filter is designed to ignore black pixels in different ways.

Table 4.1 – Different filters for ignoring black pixels in the recognition process

Filter	*DA Module*	*Knowledge Base*
None	No	No
And	Yes	Yes
Or	Yes	Yes
Kinect	Yes	No
Library	No	Yes

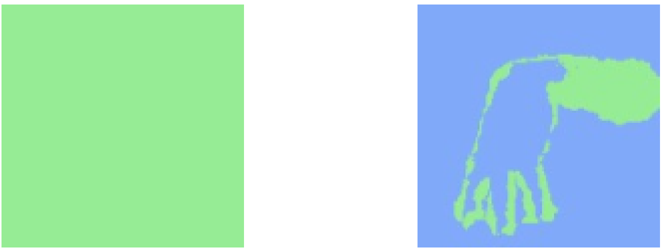
Table 4.1 shows, according to the respective filter, if the black pixel, from the *DA Module* or from the *Knowledge Base*, is ignored. Also, the following points explain how each filter works. This explanation will be based on the images of Figure 4.8, representing the letter 'M', and will use a hand variation (V_d) of 27, between images.

(a) *DA Module* image (b) *Knowledge Base* image

Figure 4.8 – Images used to illustrate how the filters work

- ***None***

The *None* filter is the initial case of study, in other words, the case where all pixels are compared. Despite not being exactly a filter, is the starting point of the algorithm and, therefore, also receives the 'filter' terminology.



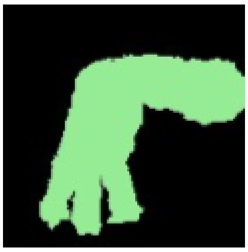
(a) Valid pixels for the recognition (b) Valid pixels after recognition

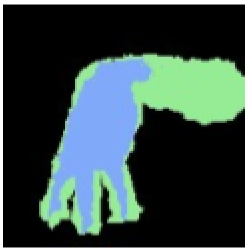
Figure 4.9 – Example of the *None* filter

In this case, all pixels are compared, as shown in light green at Figure 4.9 (a), and when the matching is conducted, it provides the results in light blue of Figure 4.9 (b). From this example, an approximation of 83,87% between both images was achieved.

- ***And***

When in the *None* filter all the pixels are matched, the other filters match only the pixels that contain relevant information, in other words, pixels that are not black. For instance, the *And* filter, makes the match when the pixels of both images are not black.



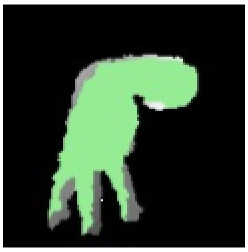


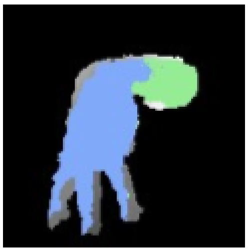
(a) Valid pixels for the recognition (b) Valid pixels after recognition
Figure 4.10 – Example of the *And* filter

When compared to Figure 4.9, the number of compared pixels in Figure 4.10 is smaller. Then, when using the *And* filter on these images, the matching results in an approximation of 47,88%, which, as expected, is worse. However, considering that only the actual hands regions are compared, the obtained approximation can be considered more accurate, since the majority of the "noise" is ignored.

- ***Or***

The *Or* filter is similar to the *And* filter, but instead of ignoring the match when both pixels are black, it ignores the matching when one of the pixels is black. In other words, if the *DA* image or the *KB* image has a black pixel the matching is skipped.





(a) Valid pixels for the recognition (b) Valid pixels after recognition
Figure 4.11 – Example of the *Or* filter

With a total of 3.909 pixels matched, the approximation between both images is 78,61%. Also, from the base image of the *DA Module*, it is clear that valid pixels are not used in the process and, therefore, it is not expected good results in terms of accuracy from this filter.

- ***Kinect***

Other filters were designed based on the actual images, not on the combination of both. The *Kinect* filter is the first example of that. It ignores the black pixels present on the image provided by the *DA Module*, or, as the filter name implies, the image that comes from the *Kinect Sensor*.

(a) Valid pixels for the recognition (b) Valid pixels after recognition
Figure 4.12 – Example of the *Kinect* filter

With this filter, the valid pixels, illustrated on Figure 4.12 (a), are based on the image from the *DA Module*, Figure 4.8 (a), then they are the same. When conducting the match on the example, the determined approximation is 64,10%.

- ***Library***

The last filter to be implemented is the *Library* filter. Here, as the opposite of the *Kinect* filter, the image that has the pixels ignored is the image from an existing library of images from the *KB*.

(a) Valid pixels for the recognition (b) Valid pixels after recognition
Figure 4.13 – Example of the *Library* filter

For the provided example, visible on Figure 4.13, this filter achieved an approximation of 55,54%.

4.3.2 SLR Implementation

Having 5 different forms of making the recognition of sign language, the process for implementing the *SLR Module* is divided into two phases:

A. The implementation of the filters and their validation

For the implementation and validation of the filters an external application is created. Thus, this new application must be capable of:

- Acquire suitable information for the construction of a robust knowledge base, used to test the filters;
- Validate the filters according to different methods, explained further in chapter 5.1.1;
- Be reusable, so that this application can be inserted on the final prototype, including the acquired knowledge base.

In order to implement the acquisition of data, on this external application, portions of the *DA Module* will be implemented.

B. The implementation of the actual module

The actual module implementation consists on the usage of the external application classes. Thus, the *SLR Module* will consist on the same implementation used during the validation of the SLR. Also, the *Knowledge Base* will benefit from this application, since it can use the most relevant portion of the information acquired during the implementation and validation of the filters.

4.4 *Game Module*

The last module to be implemented is the *Game Module*. By implementing this module, it will be possible to conduct the study that will validate or discard the proposal. In what concerns the composition of this module four blocks were idealized:

- "Sound & Music", responsible for playing sounds and music for the entire duration of the gameplay.
- "Play", used for playing the games and lessons. From the proposed architecture, this block is divided into two modes of play: 1 – *School-mode*; and 2 – *Competition-mode*;
- "Navigation", since the prototype is not only constituted by the games and lessons, also, the navigation between different pages must be taken into account (Figure 4.19); and
- "Interface", the block set as the frontend of the prototype or, in other words, the block that translate the outputs into the display.

4.4.1 "Sound & Music"

This block is used as a "support" to increase the interactivity of the game. Then it is designed as a class that provides:

- Functions to allow the start/stop of the music and sounds and the increase/decrease of the volume;
- Also, this block is used to provide the sounds to the speakers, according to mode of play.

4.4.2 "Play"

This is the block used by the player when learning or to apply sign language. Therefore, this block is viewed according with the modes:

A. *School-mode*

During *School-mode,* the player has the task of learning sign language. More accurately, he learns the alphabet and the numbers from 0 to 9. With that purpose in mind, lessons were designed to teach in two different ways:

- First by category, as visible in Figure 4.19, where the player chooses between letters and numbers;
- Second, the lessons alternate between both subjects, and so, it is continuously.

Despite being available on the serious game prototype, the used knowledge base was constructed to just support the sign language alphabet. Therefore, the lessons of numbers are unavailable to be played.

Each lesson is composed of five consecutive elements. For example, a lesson starting with letter ‘A’ will have ‘B’, ‘C’, ‘D’ and ‘E’ as the following elements. Figure 4.14 shows an example of such a lesson, where, the player must correctly reproduce the letter ‘C’ and, after a correct reproduction of this letter, the game moves to the next letter (‘D’). Also, the current letter is placed on a list on the left side of the chalk board.

Figure 4.14 – Example of a lesson during School-mode

B. *Competition-mode*

For the *Competition-mode*, the idea consists on making the player apply their knowledge on sign language. Therefore two games were created:

- The first game is called *Quiz* and is a quiz-like game.
  During this game, the player must answer multiple questions about sign language. Here, these questions refer to the lessons already taken in the *School-mode*. Also, for each question there are four possible answers, from which the user must select one by spelling that answer in sign language.

  An example of such questions is shown on Figure 4.15, where the user must answer the question “What is the symbol for the letter ‘B’?” and as possible choices it is presented four different letters in sign language. From those letters, the player reproduces one to the NUI sensor.

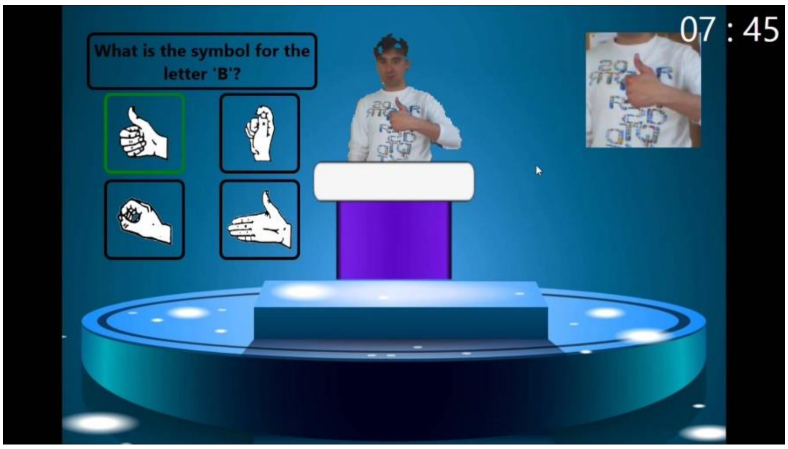


Figure 4.15 – Example of a Quiz game during Competition-mode

In the event of the answer being correctly chosen and reproduced, the game shows the answer box in green. While, on the other hand, when the answer is incorrect, the box is shown in red;

- The other game, present in the *Competition-mode*, is the *Lingo* game. By using sign language, the objective of this game is to discover a five letter word in five tries.

  As a recreation of the famous board game *MasterMind*, Figure 4.16 shows the different steps on how the game is played. Now, imagining that the user must determine the word “Album”, the steps, represented on the example are the following:

  a) As help to the player, the first letter of the wanted word is given. Thus the letter ‘A’ is presented on the initial board, as visible on Figure 4.16 (a);
  b) As the first attempt, the player spells the word “Atlas”, Figure 4.16 (b);
  c) Then it is up for the game to verify if the spelled word is the desired word.
     In order to make that verification, each letter is compared with the letters in the desired word. Thus, the result of this match, on Figure 4.16 (c), shows that:
     i. Since it is coloured in green, the first ‘A’ letter exists in the desired word and is in the right place;
     ii. There is no second letter ‘A’, since this is coloured in red. Also, there are no ‘T’ and ‘S’ in the desired word; and
     iii. The letter ‘L’ exists in the desired word but it isn’t in the right place, being coloured in yellow.
  d) After the match is concluded, the letters deemed correct, in the previous rounds, are placed in their location. Therefore, as visible on Figure 4.16 (d), letter ‘A’ is displayed in the beginning of the new word;
  e) For the second round, the player decides to spell the word ‘Bloom’, Figure 4.16 (e). This shows that, despite already having a correct letter, the player must spell the entire word in order to validate it;
  f) From this round, on Figure 4.16 (f), it is shown that:
     iv. The ‘L’ and ‘M’ letters exist in the desired word and are in the right place;
     v. Also, there is a ‘B’, but in other location; and
     vi. For last, there is no ‘O’ letters.
  g) In the beginning of this last round, the correct letters, in green on previous rounds, are placed in their location, thus creating Figure 4.16 (g);
  h) Then, the player spells ‘Album’, Figure 4.16 (h);
  i) Finally, considering that this is the correct word, the entire line is displayed in green.

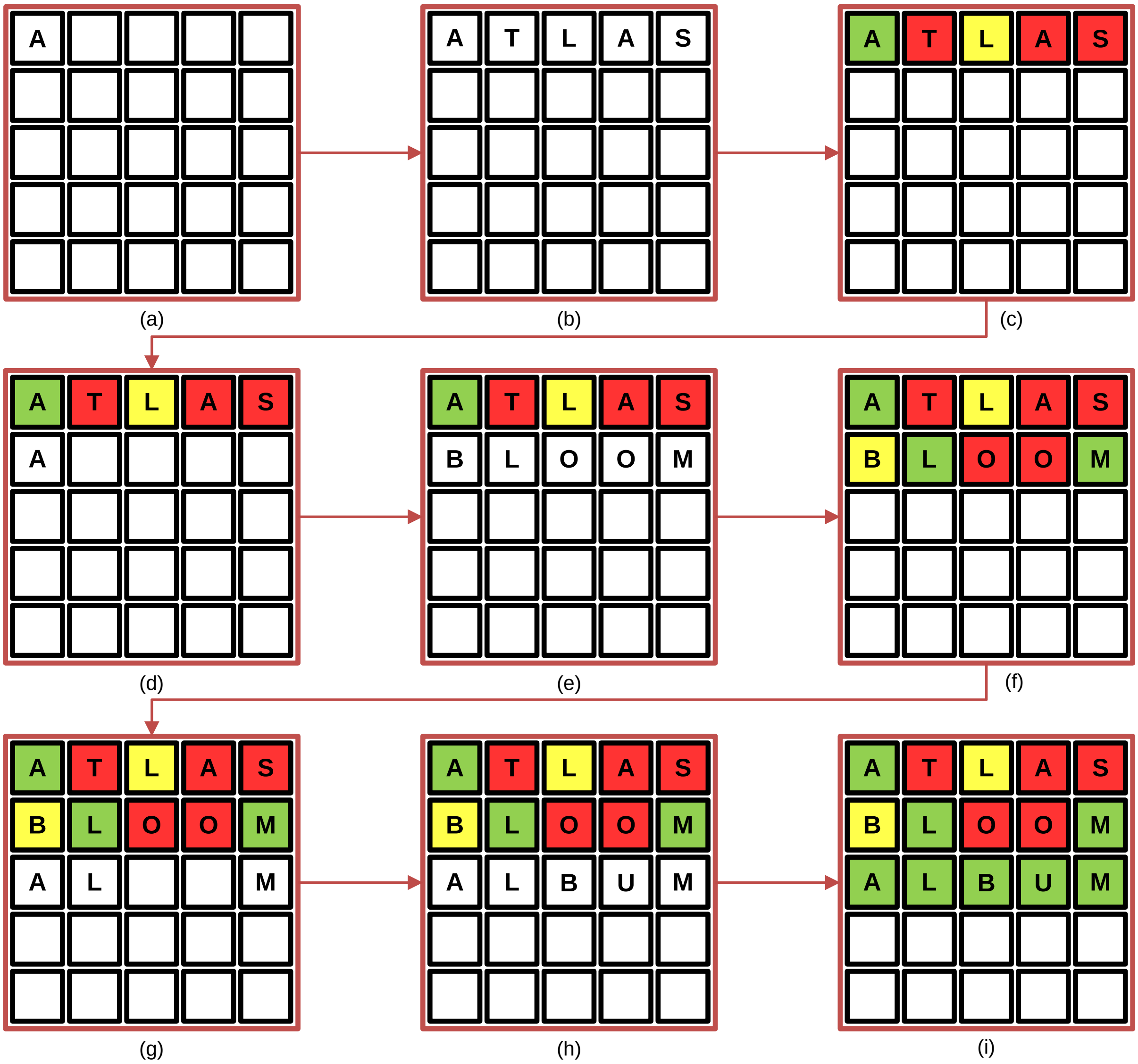


Figure 4.16 – Expected Lingo game flow

When applying this game to the prototype, the result is similar to Figure 4.17. Here, the game board is on the left side of the screen and a green screened image of the player is shown behind a stand, simulating a TV show.

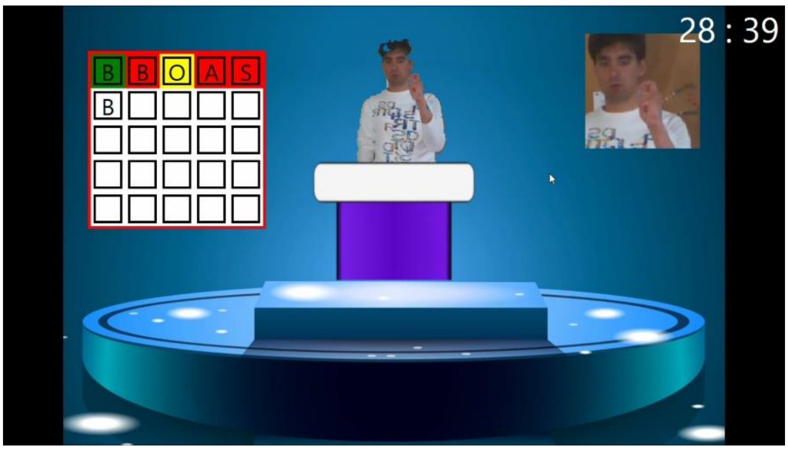


Figure 4.17 – Example of a Lingo game during Competition-mode

4.4.3 “Navigation”

In what concerns the “Navigation” block, as stated before, it refers to the phases between games. Therefore, three examples of these phases will be shown, in order to explain the implementation of this block.

1. User Selection Page

This is the first page in the “Navigation” block. It is responsible for the selection of the user. Here, while on this page, the user is capable of selecting a player, visible on Figure 4.18, or, if he has not created a player yet, he can either create a new one or use the guest mode.

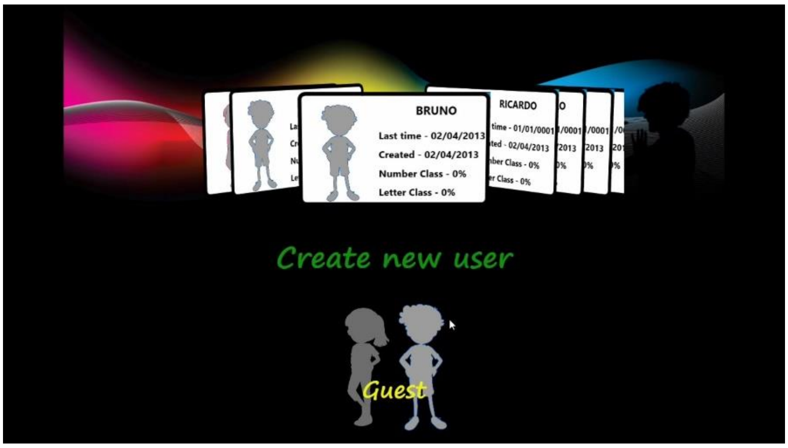


Figure 4.18 – Initial menu of the prototype

The creation of such a page is justified by the possibility of keeping track of the learning progress and the scores obtained in the multiple games. Also, it can be used for new players to try the prototype.

2. Home Page

This page, Figure 4.19, consists on the menus that are capable of controlling the prototype. Thus, five buttons, to support the different functionalities, where implemented. These five buttons are:

- “School” – which provides the path to the two forms of lessons;
- “Games” – is the button that is used to go into *Competition-mode* and play a game. That selection happens similarly to the button for the Category in Figure 4.19. After selecting a game, three difficulty levels (Easy, Medium and Hard) are presented to the user;
- “User” – this button is used for presenting results and status. For example, to present the status of lessons already attended. Nevertheless, despite being inserted into the main menu, this functionality was not fully implemented into the game and, therefore, is currently unavailable;
- “Settings” – as presented in most games, this button is used for changing the settings of the prototype. An example is changing on and off sound and music. However, this button functionality was not concluded by the time this dissertation is presented;
- “Exit” – this button allows the user to exit the game or to exit the selected character.

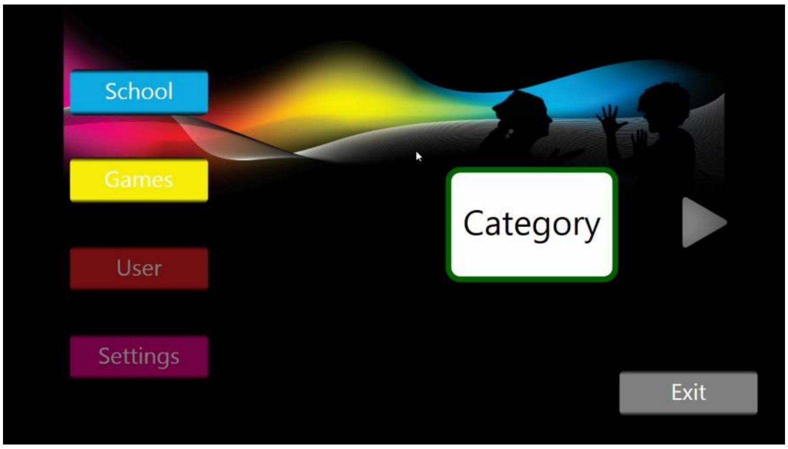


Figure 4.19 – Menu to choose different types of School-mode functionalities

3. School Page

The third example of navigation is the page for choosing a lesson, as shown in Figure 4.20. In this menu, the sequence of available lessons is presented. In this sequence, only after a lesson is completed that the next lesson becomes available. Still, the user can always repeat lessons that were previously completed.

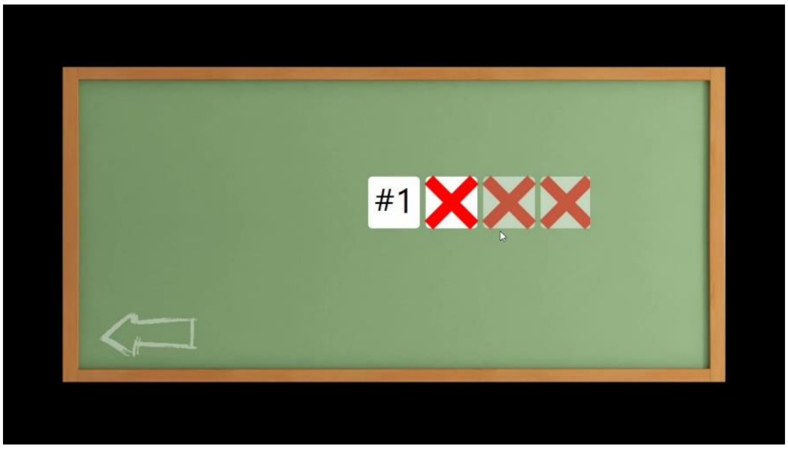


Figure 4.20 – Menu to choose the number of the lesson

4.5 Summary

The current chapter provided an overview of the implementation required in order to validate the proposal. This chapter also serves as a more profound explanation of Chapter 3.1, where the used toolswere selected and the modules, that compose the prototype, were described.

In terms of the tools and resources required to implement a prototype of the proposal, it was selected one resource: the *Kinect Sensor*; and three tools: 1- the *Kinect SDK*; 2 – *Microsoft Visual Studio*, as the IDE where the prototype is implemented; and 3 – *Emgu CV*, an image processing wrapper, which is used to assist in the SLR process.

For the implemented modules, the description is made on how they operate. For instance, it was displayed the process for acquiring a standardized image. Also, it was verified that matching entire images can cost time. This can create a system that does not work well in real-time. Therefore, filters were implemented to ease the recognition. Nonetheless, a validation of those filter are required, prior to the usage of those. To conclude the modules it was described how the player interacts with the prototype. For it, examples of the lessons, games and menus were provided.

The following chapter presents the validation of this dissertation proposal. In it, the validation of the *SLR Module* is presented, through the conduction of a quantitative study. In what concerns the proposal, a qualitative study is going to be applied.

5. Validation

After implementing a prototype, it is necessary to conduct the study that will validate the proposal. However, just like described in Chapter 4, the validation on this prototype is divided into two parts. First, the *SLR Module* must be validated and, from it the best filter, hand variation and approximation are determined. Secondly, the actual implemented prototype is validated. Therefore, this chapter consists on the presentation of the validation method and the obtained results.

5.1 Sign Language Recognition

According to the proposed architecture, this module is responsible for recognizing sign language letters from standardized images. However, due to the amount of pixels to match, the recognition process was divided into five different filters, designed to ignore black pixels. In the following sections the method of validation is described, followed by the obtained results and an interpretation of those results.

5.1.1 Method

In order to validate the *SLR Module* a quantitative method of validation was devised. This method proposes the selection of a filter, a hand variation value (ranging from 1 to 50) and an approximation value that best fit the validation users. Then, this validation is conducted with the assistance of four persons and is based on three different datasets:

- The first dataset is the data used to create the image library. In this 'Library Data', it will be stored three sets of 100 images for each person. Also, for each set the distances from the Kinect sensor vary (1 meter, 1.5 meters and 2 meters);
- The second dataset is called 'Static Data'. This data is composed of three sets of 2 images, with the same distances from the Kinect sensor as in the 'Library Data';
- The final dataset, called 'Dynamic Data', is composed of three videos (also, one for each distance to the Kinect sensor). Each video is composed of 100 frames/images.

According to those datasets, this validation is divided into two phases, the static and the dynamic phase. In the next section, according to each phase of validation, the obtained results are presented.

5.1.2 Results

1. Static validation of the filters.

The first phase of validation consists on using the 'Static Data' and compare it with the 'Library Data', for all five filters and all hand distances. From those variables, it is expected to obtain accuracy values that can be used to determine the three best filters and the five best hand variation values, used later on the dynamic phase.

Then, the process for determining those values is described by showing examples of the obtained results for a randomly selected letter. This process is divided into four stages and works as follows:

- The first stage consists on comparing each static image with the 'Library Data'. Examples of those results are shown on Table 5.1.

Table 5.1 – Portion of approximation and accuracy results of letter 'J', using image 1 of user 1

Storage	Character Data					Entire 'Library Data'									
Filter	*None*	*And*	*Or*	*Kinect*	*Library*	*None*		*And*		*Or*		*Kinect*		*Library*	
Variation	Approximation					Sign	Appr	Sign	Appr	Sign	Appr	Sign	Appr	Sign	Appr
1	78,01	11,94	14,67	13,1	13,23	J	78,01	J	11,94	A	14,80	J	13,10	J	13,23
2	78,94	15,63	19,21	17,15	17,32	J	78,94	J	15,63	J	19,21	J	17,15	J	17,32
3	81,26	25,23	27,9	26,42	26,42	J	81,26	J	25,23	J	27,90	J	26,42	J	26,42
4	83,15	32,78	36,01	34,31	34,32	J	83,15	J	32,78	J	36,01	J	34,31	J	34,32
5	86,63	47,47	58,34	52,09	52,6	J	86,63	J	47,47	J	58,34	J	52,09	J	52,60

- The second stage represents the averaging of all image results, according to the validation objectives. In other words, accuracies according filter and hand variation are obtained. Examples of such values are present on Table 5.2.

Table 5.2 – Portion of average accuracies for letter 'J', from user 1

		B	G	H	I	J	K	S	T	U	V	W
Filter	None	0,00	0,33	0,00	0,00	69,67	0,00	6,33	0,00	3,33	10,67	5,67
	And	0,00	6,00	1,00	0,00	81,33	0,00	1,00	0,00	2,67	0,00	6,00
	Or	6,67	5,00	3,33	0,33	65,00	0,67	6,00	0,33	2,67	0,00	0,33
	Kinect	0,00	0,33	1,00	0,00	79,33	0,00	1,00	0,00	11,00	0,00	0,67
	Library	0,00	8,00	2,33	0,00	77,00	0,00	3,67	0,00	0,00	2,33	4,33
	Average	1,33	3,93	1,53	0,07	74,47	0,13	3,60	0,07	3,93	2,60	3,40
Hand Variation	10	3,33	0,00	6,67	0,00	76,67	0,00	0,00	0,00	3,33	0,00	0,00
	11	3,33	3,33	3,33	0,00	73,33	0,00	0,00	0,00	3,33	0,00	0,00
	12	3,33	6,67	3,33	0,00	73,33	0,00	0,00	0,00	10,00	0,00	0,00
	13	6,67	6,67	3,33	0,00	63,33	0,00	6,67	0,00	10,00	0,00	0,00
	14	3,33	10,00	0,00	0,00	66,67	0,00	6,67	0,00	6,67	0,00	0,00
	15	3,33	10,00	0,00	0,00	66,67	0,00	6,67	0,00	3,33	0,00	0,00
	16	3,33	10,00	0,00	0,00	73,33	0,00	6,67	0,00	3,33	0,00	0,00
	17	0,00	10,00	0,00	0,00	80,00	0,00	0,00	0,00	3,33	0,00	3,33
	18	0,00	10,00	0,00	0,00	80,00	0,00	0,00	0,00	3,33	0,00	3,33
	19	0,00	10,00	0,00	0,00	80,00	0,00	0,00	0,00	3,33	0,00	3,33
	20	0,00	10,00	0,00	0,00	80,00	0,00	3,33	0,00	3,33	0,00	0,00
	Average	1,33	3,93	1,53	0,07	74,47	0,13	3,60	0,07	3,93	2,60	3,40

- The following stage is done by compiling the results from each user. Then by compiling the results of Table A.1 to Table A.8, the tables that average the accuracies according to the filter and according to the hand variation for each user, it results on the Table 5.3.

Table 5.3 – Acquired values from testing the *SLR Module* with the 'Static Data'

User	Filters						Hand Variations									
		Acc		Acc		Acc		Acc		Acc		Acc		Acc		Acc
1	None	72,7	And	70,6	Library	66,9	18	69,9	19	69,7	17	68,2	20	68,2	21	67,6
2	None	72,5	And	70,0	Library	67,8	27	74,9	16	73,3	11	72,5	10	71,9	41	71,8
3	None	72,7	And	71,4	Library	68,5	16	74,2	13	73,8	39	73,3	27	72,9	11	71,8
4	None	72,1	And	71,6	Library	70,0	10	75,8	12	74,1	26	73,4	15	73,1	13	72,9

- The last stage consists on the averaging of all the user results and thus creating Table A.9 and Table A.10. From these tables, it is determined that the best filters are the *None*, the *And* and the *Library* filters. Also, the best hand variations are 10, 16, 19, 27 and 39.

2. Dynamic validation of the filters.

The second phase of validation consists on a simulation of real time recognition. Therefore, the videos on the 'Dynamic Data' were processed. As a continuation of the previous example, letter 'J' is used for exemplifying the validation process. Just like the static validation, this validation is composed of the following four stages:

- The first stage of this validation, consists on passing the 'Dynamic Data' through the module, either comparing with just the wanted character and with the entire 'Library Data'. A portion of those results is present on Table 5.4.

Table 5.4 – Portion of results obtained of letter 'J', using video 2 of user 1 with a hand variation of 39

	Character Data			Entire 'Library Data'						Difference		
Filter:	None	And	Library	None		And		Library		None	And	Library
Frame	Approximation			Sign	Approx	Sign	Approx	Sign	Approx	Approximation		
1	98,14	92,49	95,75	J	98,14	J	92,49	J	95,75	0,00	0,00	0,00
2	97,96	91,84	95,93	J	97,96	J	91,84	J	95,93	0,00	0,00	0,00
3	98,10	92,31	95,53	J	98,10	J	92,31	J	95,53	0,00	0,00	0,00
4	97,79	91,16	94,66	J	97,79	J	91,16	J	94,66	0,00	0,00	0,00
5	98,02	92,03	95,59	J	98,02	J	92,03	J	95,59	0,00	0,00	0,00
6	98,05	92,13	95,26	J	98,05	J	92,13	J	95,26	0,00	0,00	0,00
7	97,96	91,85	95,45	J	97,96	J	91,85	J	95,45	0,00	0,00	0,00
8	98,37	93,43	96,86	J	98,37	J	93,43	J	96,86	0,00	0,00	0,00
9	97,98	91,90	95,63	J	97,98	J	91,90	J	95,63	0,00	0,00	0,00
10	97,96	91,81	95,51	J	97,96	J	91,81	J	95,51	0,00	0,00	0,00

- Then, by averaging the results of each video, the second stage, it is obtained results for approximation and accuracy (Table 5.5).

Table 5.5 – Approximation results for the videos of letter 'J'

		39	16	10	19	27	Avg.
Approximation	None	95,37	91,92	88,62	93,04	94,35	92,66
	And	76,78	61,97	47,60	67,09	72,04	65,10
	Library	86,43	72,30	56,15	77,07	82,35	74,86
	Avg.	86,19	75,40	64,12	79,07	82,91	
Difference	None	0,71	0,92	1,07	0,92	0,97	0,92
	And	2,17	2,68	2,63	2,40	2,40	2,46
	Library	5,92	6,25	4,83	6,09	5,35	5,69
	Avg.	2,93	3,28	2,84	3,14	2,91	
Accuracy	None	73,56	69,78	66,11	73,44	72,22	71,02
	And	85,56	83,00	83,22	83,11	83,67	83,71
	Library	63,33	63,89	71,78	72,78	66,44	67,64
	Avg.	74,15	72,22	73,70	76,44	74,11	

- Afterwards, the compiling of results is conducted for each user, Table B.1 to Table B.12. This means that, according to accuracies and approximations shown on those tables it is possible to achieve the results of Table 5.6.

Table 5.6 – Acquired values when validating the *SLR Module* with the 'Dynamic Data'

User	Filter				Variation			
		Accur	Approx	Diff		Accur	Approx	Diff
1	None	64,1	93,4	1,1	19	63,2	78,4	3,4
2	None	62,6	92,0	1,5	27	63,8	80,0	3,3
3	And	61,2	66,1	3,5	27	64,5	80,5	3,2
4	None	62,8	91,6	0,9	27	93,9	81,2	3,5

- Finally, by averaging the compiled results for all users (Table B.13, Table B.14 and Table B.15), it is concluded that the best values are:
  1. The *And* filter, due to the cost of the *None* filter, which presents an average accuracy of 61,6% and an average approximation of 80,9 ± 3,4%;
  2. 27 as the best hand variation value, which presents an average accuracy of 63,5% and an average approximation of 64,6 ± 3,5%; and
  3. An approximation value of 65%. This threshold is set as the round value of the lowest accuracy achieved between the best filter and the best hand variation.

5.2 Serious Game

The main study is conducted on the serious game prototype. For it, a qualitative validation is done because, when studying the proposal, the opinion of the final users is the most relevant resource for validation purposes. Therefore, a questionnaire is created to provide feedback on the prototype multiple features.

5.2.1 Method

This validation method, consists on the evaluation of the prototype by ten players. This evaluation corresponds to a questionnaire, composed of three parts: *Overall*, *Lessons* and *Games*, answered after experimentation of the prototype. Thus, for each question the player must give a value between 1 and 10.

5.2.2 Results

After this validation, the obtained results were compiled into Table 5.7.

Table 5.7 – Results obtained with the questionnaire

	Question	Average	Mode	Standard Deviation	Confidence Interval
Overall	Did you enjoy playing Kinect-Sign?	6,9	7	1,04	0,32
	Is the game useful to learn sign language?	6,6	6	0,92	0,31
	Did you find the game interface suitable?	7,9	8	1,14	0,33
	Are the game controllers adequate?	6,5	6	1,02	0,32
	· Mouse & Keyboard?	6,9	6	0,83	0,29
	· Kinect Sensor?	6,2	6	0,98	0,31
	Did you find the game concept interesting?	8,6	8	0,66	0,26
	Will you be coming back for more?	4,1	4	1,04	0,32
	Do you want to learn more about sign language?	4,9	5	0,83	0,29
Lessons	Did you enjoy the lessons?	5,4	5	1,02	0,32
	Are the lessons adequate to teach sign language?	6,5	7	1,20	0,33
	Are they easy to understand?	7,3	8	1,19	0,33
	Did you find the lesson interface suitable?	8,0	9	1,18	0,33
	Are the game controllers adequate for the lesson?	6,9	7	0,94	0,31
	· Mouse & Keyboard?	6,7	7	0,90	0,30
	· Kinect Sensor?	7,1	7	0,94	0,31
Games	Are the games adequate to the lessons learned?	7,1	6	1,04	0,32
	Are the games easy to understand?	6,2	7	1,66	0,33
	Did you have fun playing them?	6,1	6	0,94	0,31
	Did you find the game interface suitable?	7,8	8	1,25	0,34
	Are the game controllers adequate for the games?	5,6	5	0,92	0,31
	· Mouse & Keyboard?	6,2	6	1,25	0,34
	· Kinect Sensor?	4,5	4	0,81	0,29
	Would you find interesting to play other classic games adapted to PSL?	7,4	7	1,20	0,33

In these results some statistic values, such as the confidence interval, through normal distribution, are included. And, from those, the following points can be concluded:

- The presented concept is really interesting;
- The application prototype still needs improvement;
- The prototype is considered useful for learning sign language;
- The provided games are more entertaining than the lessons;
- The usage of the Kinect sensor is much more adequate during the lessons than during the games;
- The designed interface presents good quality;
- To conclude, the lessons are easier to understand than the provided games.

6. Concluding

Despite the need to improve some points, the presented dissertation showed that it is possible to teach sign language through the usage of serious games. Thus, the current chapter presents general conclusions, some related work, developed during this dissertation, and some possible paths of future work.

6.1 Proposal

The proposed study embraces three research fields: Sign Language, Serious Games and Natural User Interfaces. By combining those fields, it is proposed the teaching of sign language through the usage of serious games.

In order to validate this proposal, it is required the development of a prototype capable of embracing all the fields of interest. For that reason, a serious game prototype, where the user can play/learn sign language through a NUI sensor, was designed, developed and tested / validated.

This validation was composed of two parts:

1. The validation of the module responsible for sign language recognition (*SLR Module*).
   Due to the recognition process, this module is constructed based on a equation and filters, for ignoring black pixels. Then, the constant values of that equation and the filters must be put under validation, so that only the best values are used on the validation of the final prototype; And,
2. The validation of the serious game prototype.
   Considered that the intent of this proposal is to teach sign language, the objective of this validation is to conclude if the player actually learned sign language. Therefore, the validation will be based on a questionnaire made to the players of this prototype.

6.2 General Conclusions

Having two different parts to validate, it was necessary to validate each part accordingly. Thus, for the first validation it was necessary to determine the best filter, hand variation and approximation threshold to use on the serious game. The prototype was then validated through a questionnaire. The following points show the obtained results/conclusions obtained during validation:

- For the SLR validation it was determined that, the best filter is the *And* filter, the best hand variation is 27 and the approximation threshold is 65%;
- Then, on the proposal prototype validation it was verified that:
  - The presented concept is really interesting;
  - The prototype is considered useful for learning sign language; and,
  - The Kinect sensor functions better during the lessons than during the games.

Althought not being a final product, since multiple functionalities of the game were not fully implemented, this prototype provides an example on how a serious game could be in a market application. Nevertheless, this prototype already provides good feedback on how a game of such type should be implemented.

As a final note, it was noticed, during implementation, that if the user playing the game is the same that constructed the image library, then the recognition results are more accurate. Thus, the players that validated the proposal are not the same users that validated the *SLR Module*.

6.3 Parallel Work

During the development of this research work, the following parallel work was conducted:

- Participation on Microsoft Imagine Cup 2012, achieving the national finals in the category of *Games* (Morais, Morais, Maia, Gameiro, & Galveia, 2014);
- Participation on the multimodal interfaces workshop eNTERFACE'13, which concluded on a chapter of the book Innovative and Creative Developments in Multimodal Interaction Systems (Gameiro, Cardoso, & Rybarczyk, 2014);
- Poster publication on the Conference on Electronics, Telecommunications and Computers 2013, (Gameiro, Cardoso, & Rybarczyk, 2013).

6.4 Future Work

According to the obtained results, it is clear that the serious game prototype still lacks in the engaging factor. For that reason, one path for future work can be the introduction of a 3D environment designed for interaction through sign language.

Other points that can be improved in the proposal are the *School-mode* and the *Competition-mode*. An example is the expansion of the *School-mode* in order to support evaluations to the lessons. In the case of the *Competition-mode*, other games, such as *Battleship*, can be introduced or a multiplayer feature that allows the competition between two players.

In what concerns the *Sign Language Recognition Module*, the path of improvement must go beyond the current recognition of the sign language alphabet. Thus, this path can follow two different directions:

1. The improvement of the static recognition by the introduction of machine learning algorithms, such as the algorithms presented on the work of (Correia, 2013);
2. Or, the introduction of dynamic recognition capable of recognizing moving gestures, such as the work conducted by (Chai, et al., 2013).

7. References

About. (2010). (Spongelab Biology) Retrieved February 23, 2014, from http://www.genomicsdigitallab.com/gdl/default.cfm?thePage=CA/about

Berke, J. (2010, November 6). *Challenges of Learning Sign Language*. Retrieved January 21, 2014, from About.com: http://deafness.about.com/od/learningsignlanguage/a/hardtolearnsign.htm

Bingo. (2014, March 27). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Bingo_(U.S.)

Breuer, J. S., & Bente, G. (2010). Why so serious? On the relation of serious games and learning. *Eludamos. Journal for Computer Game Culture, 4*, 7-24.

Broy, N., & Rümelin, S. (2012). Natural Visual User Interfaces - Beyond Input Modalities. *4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI'12)*, (pp. 61-63). Portsmouth. Retrieved March 10, 2014, from http://www.auto-ui.org/12/adjunct-proceedings/w1-07-broy.pdf

Captain Novolin. (2014, 09 06). (Giant Bomb) Retrieved March 10, 2014, from http://www.giantbomb.com/captain-novolin/3030-4948/

Chai, X., Li, G., Lin, Y., Xu, Z., Tang, Y., Chen, X., & Zhou, M. (2013). *Sign Language Recognition and Translation with Kinect.* Institute of Computing Technology, Key Lab of Intelligent Information Processing of Chinese Academy of Sciences, Beijing, China.

Correia, M. M. (2013). *Reconhecimento de Elementos da Língua Gestual Portuguesa com Kinect.* Retrieved August 19, 2013, from http://paginas.fe.up.pt/~ee06160/thesis/

Costa, R. (2013, July 22). *Superfícies Interativas com Kinect*. Retrieved February 23, 2014, from http://repositorio-aberto.up.pt/bitstream/10216/68055/2/954479.pdf

Deaf, W. F. (2014). *FAQ*. Retrieved January 21, 2014, from World Federation of the Deaf: http://wfdeaf.org/faq

Deaf, W. F. (2014). *Human Rights*. Retrieved January 21, 2014, from World Federation of the Deaf: http://wfdeaf.org/human-rights

Depth Sensor Shootout: Kinect, Leap, and Intel. (2013, April). (Stimulant) Retrieved August 22, 2013, from http://stimulant.io/wp/index.php/blog/2013/04/depth-sensor-shootout/

Djaouti, D., Alvarez, J., Jessel, J.-P., & Rampnoux, O. (2011). *Origins of Serious Games.* France.

Gameiro, J., Cardoso, T., & Rybarczyk, Y. (2013). Kinect-Sign: Teaching sign language to "listeners" through a game. *Conference on Electronics, Telecommunications and Computers* (p. 36). Lisbon: Elsevier Journal PROCEDIA TECHNOLOGY. Retrieved from http://www.adeetc.isel.pt/cetc13/Book%20of%20Abstracts/Poster%202/cetc2013_submission_120.pdf

Gameiro, J., Cardoso, T., & Rybarczyk, Y. (2014). Kinect-Sign: Teaching Sign Language to "Listeners" through a Game. In Y. Rybarczyk, T. Cardoso, J. Rosas, & L. M. Camarinha-Matos, *Innovative and Creative Developments in Multimodal Interaction Systems* (pp. 141-159). Lisbon: Springer Berlin Heidelberg. doi:10.1007/978-3-642-55143-7_6

Graphical user interface. (2014, March 7). (Wikipedia) Retrieved March 10, 2014, from http://en.wikipedia.org/wiki/Graphical_user_interface

Grossman, L. (2005, February 21). *The Army's Killer App*. (Time, Editor) Retrieved February 6, 2014, from Time: http://content.time.com/time/magazine/article/0,9171,1029872,00.html

Integrated development environment. (2014, February 8). (Wikipedia) Retrieved February 23, 2014, from Wikipedia: http://en.wikipedia.org/wiki/Integrated_development_environment

Intel Software. (2013). *The Intel Perceptual Computing SDK 2013*. (Intel) Retrieved August 22, 2013, from http://software.intel.com/en-us/vcsource/tools/perceptual-computing-sdk

Jensen, M. B. (2011). *Natural user interfaces from all angles.* Master Thesis, Aalborg Universitet, Department of Architecture, Design and Media Technology. Retrieved March 2014, 10, from http://projekter.aau.dk/projekter/files/52687173/Natural_interfaces_from_all_angles_Michael_B._Jensen.pdf

Kinect. (2013, August 13). (Wikipedia) Retrieved August 22, 2013, from Wikipedia: http://en.wikipedia.org/wiki/Kinect

Krystalli, P., Arvanitis, P., & Panagiotidis, P. (n.d.). *Evaluating Serious Games for Foreign Language Learning: An Online Grading and Visualization Tool.* Aristotle University of Thessaloniki, School of French.

Leap Motion. (2013, August 15). (Wikipedia) Retrieved August 22, 2013, from http://en.wikipedia.org/wiki/Leap_Motion

Lingo (U.S. game show). (2013, August 12). (Wikipedia) Retrieved August 21, 2013, from Wikipedia: http://en.wikipedia.org/wiki/Lingo_(U.S._game_show)

Main Page. (2013, August 33). Retrieved February 10, 2014, from Emgu CV: http://www.emgu.com/wiki/index.php/Main_Page

Microsoft Visual Studio. (2014, February 22). (Wikipedia) Retrieved February 23, 2014, from Wikipedia: http://en.wikipedia.org/wiki/Visual_studio

Morais, J., Morais, R., Maia, G., Gameiro, J., & Galveia, B. (2014, 09 19). *Kinect-Sign - Imagine Cup 2013*. Retrieved from You Tube: https://www.youtube.com/watch?v=Zep4ZCyGuN4

Most Popular Video Games of all The Time. (2014, January 28). (Uniworld News) Retrieved March 10, 2014, from http://www.uniworldnews.org/most-popular-video-games-of-all-the-time/

NUI. (2012, July 26). (TechTerms.com) Retrieved March 10, 2014, from TechTerms.com: http://www.techterms.com/definition/nui

OpenCV. (2010, November 30). Retrieved February 10, 2014, from Emgu CV: http://www.emgu.com/wiki/index.php/OpenCV

Organization, W. H. (2013, February). *Deafness and hearing loss*. (World Health Organization) Retrieved October 2, 2013, from http://www.who.int/mediacentre/factsheets/fs300/en/

Revolutionary User Interfaces. (2013). (Knight Lab) Retrieved March 10, 2014, from Timeline JS: http://timeline.knightlab.com/examples/user-interface/

Sign the Alphabet. (2011). (Funbrain) Retrieved August 23, 2013, from Fun Brain: http://www.funbrain.com/signs/

Sign-O. (2007). Retrieved from http://www.amazon.com/Sign-ASL-Bing-Game-Deaf/dp/B003AX6VO8

Silva, A., Mamede, N., Ferreira, A., Baptista, J., & Fernandes, J. (2011). *Towards a Serious Game for Portuguese Learning*. Retrieved March 11, 2014, from http://www.inesc-id.pt/pt/indicadores/Ficheiros/7522.pdf

Sorensen, B. H., & Meyer, B. (2007). *Serious Games in language learning and teaching - a theoretical perspective.* The Danish University of Education, Department of Educational Anthropology. Copenhagen: DiGRA.

Starner, T. E. (1995). *Visual Recognition of American Sign Language Using Hidden Markov Models.* Retrieved August 24, 2013, from http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA344219

Stewart, J., & Misuraca, G. (2013). *The Industry and Policy Context for Digital Games for Empowerment and Inclusion: Market Analysis, Future Prospects and Keyu Challenges in Videogames, Serious Games and Gamification.* European Commission, Institute for Prospective Technological Studies. Seville (Spain): Joint Research Center. Retrieved January 2014, 28, from http://ftp.jrc.es/EURdoc/JRC77656.pdf

Surdos, A. P. (2011). *Comunidade*. Retrieved October 2, 2013, from Associação Portuguesa de Surdos: http://www.apsurdos.org.pt/index.php?option=com_content&view=article&id=43&Itemid=57

Surdos, A. P. (2011). *Língua Gestual*. Retrieved January 22, 2014, from Associação Portuguesa de Surdos: http://www.apsurdos.org.pt/index.php?option=com_content&view=article&id=41&Itemid=56

Susi, T., Johannesson, M., & Backlund, P. (2007). *Serious Games: An Overview.* University of Skövde, School of Humanities and Informatics. Skövde: Institutionen för kommunikation och information. Retrieved January 21, 2014, from http://his.diva-portal.org/smash/record.jsf?pid=diva2:2416

Ulicsak, M., & Wright, M. (2010, June). *Games in Education: Serious Games*. (Futurelab) Retrieved February 23, 2014, from http://media.futurelab.org.uk/resources/documents/lit_reviews/Serious-Games_Review.pdf

University, G. (2014, September 15). *ASL-English Bilingual Education*. Retrieved January 22, 2014, from https://www.gallaudet.edu/clerc_center/information_and_resources/info_to_go/educate_children_(3_to_21)/resources_for_mainstream_programs/language_and_communication/asl-english_bilingual_education.html

User Interface. (2009, March 31). (TechTerms.com) Retrieved March 10, 2014, from http://www.techterms.com/definition/user_interface

Windows Presentation Foundation. (2014, February 23). (Wikipedia) Retrieved February 23, 2014, from http://en.wikipedia.org/wiki/Windows_Presentation_Foundation

Winnie, T., & Drennan, A. (2008). *Sign Language Bingo*. Retrieved August 23, 2013, from http://www.superduperinc.com/products/view.aspx?pid=bgo133&s=sign-language-bingo#.UheEIxtwquI

Appendix A – Results of the SLR Module during Static Validation

Table A.1 Average of accuracies, according to the filter, obtained for user 1

Filter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
None	**85,3**	**98,7**	**93,3**	**100,0**	**84,7**	**79,0**	**53,3**	**30,0**	**81,7**	**69,7**	**77,3**	**91,7**	**80,7**	**87,0**	**55,0**	**100,0**	**95,7**	**59,7**	**79,3**	**61,0**	**69,3**	**43,7**	**82,0**	**21,3**	**67,0**	**43,0**	**72,7**
And	**86,0**	**95,7**	**90,7**	**94,0**	**86,7**	**70,3**	**53,7**	**32,0**	**84,3**	**81,3**	**67,3**	**84,7**	**94,0**	**62,3**	**48,7**	**86,3**	**92,7**	**67,7**	**75,3**	**56,3**	**65,0**	**49,3**	**82,0**	**19,0**	**75,7**	**34,0**	**70,6**
Or	59,7	68,7	80,3	89,7	64,7	45,3	44,0	25,0	58,7	65,0	30,3	66,0	23,3	25,3	20,3	61,0	72,7	31,7	71,3	24,3	39,0	37,0	37,7	24,7	43,0	34,3	47,8
Kinect	45,3	87,7	84,3	85,0	52,7	23,7	30,3	23,7	53,0	79,3	51,0	73,3	93,7	41,0	28,3	86,0	96,0	65,7	71,0	61,7	66,7	43,0	75,0	32,0	94,7	23,3	60,3
Library	**84,7**	**95,0**	**87,0**	**94,7**	**88,3**	**77,0**	**59,0**	**37,7**	**82,3**	**77,0**	**69,0**	**78,7**	**90,0**	**61,7**	**37,3**	**88,7**	**83,7**	**48,0**	**78,7**	**31,7**	**66,3**	**38,7**	**68,7**	**21,7**	**57,3**	**36,0**	**66,9**
Avg.	72,2	89,1	87,1	92,7	75,4	59,1	48,1	29,7	72,0	74,5	59,0	78,9	76,3	55,5	37,9	84,4	88,1	54,5	75,1	47,0	61,3	42,3	69,1	23,7	67,5	34,1	

Table A.2 Average of accuracies, according to the hand variation, obtained for user 1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
1	96,7	93,3	83,3	93,3	60,0	56,7	70,0	36,7	50,0	83,3	73,3	10,0	73,3	30,0	46,7	60,0	73,3	26,7	63,3	33,3	56,7	50,0	46,7	20,0	33,3	50,0	56,5
2	86,7	90,0	90,0	90,0	70,0	50,0	70,0	46,7	56,7	66,7	53,3	36,7	73,3	66,7	33,3	50,0	83,3	33,3	86,7	30,0	53,3	50,0	63,3	33,3	50,0	46,7	60,0
3	96,7	96,7	93,3	96,7	66,7	53,3	60,0	46,7	73,3	63,3	50,0	46,7	73,3	46,7	23,3	53,3	80,0	36,7	76,7	33,3	53,3	60,0	56,7	43,3	63,3	46,7	61,2
4	86,7	96,7	96,7	86,7	63,3	56,7	63,3	46,7	73,3	66,7	60,0	60,0	70,0	40,0	26,7	46,7	73,3	43,3	83,3	26,7	66,7	63,3	66,7	36,7	60,0	50,0	61,9
5	86,7	80,0	93,3	100,0	60,0	56,7	60,0	46,7	80,0	63,3	46,7	70,0	66,7	43,3	20,0	80,0	70,0	43,3	80,0	30,0	60,0	63,3	66,7	36,7	56,7	60,0	62,3
6	76,7	60,0	76,7	96,7	66,7	60,0	63,3	33,3	83,3	50,0	46,7	73,3	63,3	43,3	26,7	76,7	76,7	43,3	83,3	33,3	63,3	66,7	66,7	43,3	70,0	50,0	61,3
7	63,3	60,0	86,7	100,0	63,3	70,0	60,0	26,7	76,7	63,3	63,3	76,7	66,7	43,3	26,7	93,3	80,0	36,7	80,0	40,0	50,0	56,7	76,7	46,7	56,7	56,7	62,3
8	66,7	66,7	86,7	100,0	63,3	56,7	53,3	26,7	73,3	70,0	53,3	73,3	80,0	46,7	26,7	86,7	83,3	43,3	83,3	43,3	50,0	36,7	70,0	36,7	66,7	56,7	61,5
9	40,0	86,7	83,3	100,0	73,3	56,7	53,3	23,3	63,3	76,7	40,0	80,0	76,7	53,3	33,3	93,3	80,0	40,0	83,3	56,7	60,0	50,0	63,3	30,0	70,0	46,7	62,1
10	46,7	90,0	80,0	100,0	73,3	53,3	56,7	20,0	66,7	76,7	30,0	83,3	66,7	50,0	30,0	93,3	80,0	43,3	83,3	53,3	63,3	43,3	46,7	26,7	70,0	46,7	60,5
11	63,3	86,7	83,3	100,0	70,0	50,0	53,3	26,7	76,7	73,3	30,0	80,0	70,0	50,0	30,0	93,3	66,7	40,0	83,3	43,3	50,0	46,7	56,7	23,3	66,7	40,0	59,7
12	56,7	86,7	80,0	100,0	76,7	43,3	53,3	20,0	76,7	73,3	43,3	56,7	66,7	50,0	30,0	93,3	66,7	43,3	83,3	43,3	60,0	36,7	60,0	23,3	56,7	33,3	58,2
13	60,0	80,0	70,0	100,0	76,7	46,7	53,3	20,0	76,7	63,3	60,0	63,3	70,0	46,7	30,0	96,7	60,0	40,0	83,3	26,7	56,7	30,0	63,3	23,3	56,7	36,7	57,3
14	63,3	83,3	70,0	100,0	80,0	40,0	50,0	20,0	83,3	66,7	70,0	70,0	70,0	70,0	30,0	96,7	63,3	40,0	83,3	26,7	46,7	30,0	53,3	26,7	60,0	33,3	58,7
15	66,7	90,0	83,3	100,0	80,0	43,3	56,7	33,3	90,0	66,7	63,3	80,0	70,0	66,7	30,0	96,7	60,0	50,0	83,3	30,0	50,0	36,7	46,7	26,7	53,3	50,0	61,7
16	66,7	96,7	86,7	100,0	90,0	50,0	50,0	33,3	86,7	73,3	56,7	80,0	66,7	60,0	30,0	93,3	93,3	56,7	76,7	43,3	46,7	33,3	63,3	26,7	66,7	43,3	64,2
17	**73,3**	**96,7**	**86,7**	**100,0**	**86,7**	**60,0**	**66,7**	**40,0**	**93,3**	**80,0**	**60,0**	**83,3**	**66,7**	**60,0**	**30,0**	**96,7**	**93,3**	**53,3**	**80,0**	**50,0**	**60,0**	**50,0**	**60,0**	**36,7**	**70,0**	**40,0**	**68,2**
18	**73,3**	**96,7**	**86,7**	**100,0**	**93,3**	**63,3**	**63,3**	**40,0**	**90,0**	**80,0**	**70,0**	**86,7**	**70,0**	**63,3**	**30,0**	**96,7**	**93,3**	**50,0**	**80,0**	**53,3**	**70,0**	**50,0**	**76,7**	**33,3**	**73,3**	**33,3**	**69,9**
19	**76,7**	**96,7**	**86,7**	**100,0**	**76,7**	**60,0**	**60,0**	**46,7**	**90,0**	**80,0**	**63,3**	**80,0**	**73,3**	**60,0**	**33,3**	**100,0**	**100,0**	**50,0**	**80,0**	**56,7**	**76,7**	**36,7**	**80,0**	**36,7**	**76,7**	**36,7**	**69,7**
20	**66,7**	**96,7**	**83,3**	**100,0**	**80,0**	**60,0**	**60,0**	**40,0**	**90,0**	**80,0**	**73,3**	**76,7**	**70,0**	**46,7**	**33,3**	**93,3**	**100,0**	**60,0**	**83,3**	**53,3**	**76,7**	**36,7**	**76,7**	**30,0**	**70,0**	**36,7**	**68,2**
21	**60,0**	**96,7**	**83,3**	**100,0**	**73,3**	**60,0**	**53,3**	**30,0**	**73,3**	**80,0**	**73,3**	**86,7**	**73,3**	**56,7**	**30,0**	**96,7**	**100,0**	**60,0**	**80,0**	**60,0**	**66,7**	**46,7**	**83,3**	**23,3**	**73,3**	**36,7**	**67,6**
22	63,3	93,3	83,3	93,3	73,3	60,0	53,3	30,0	73,3	80,0	66,7	80,0	73,3	50,0	36,7	100,0	100,0	53,3	80,0	56,7	63,3	43,3	76,7	20,0	70,0	33,3	65,6

23	70,0	93,3	83,3	96,7	80,0	60,0	53,3	30,0	73,3	80,0	63,3	83,3	70,0	46,7	36,7	93,3	100,0	53,3	83,3	56,7	63,3	46,7	76,7	20,0	73,3	36,7	66,3
24	70,0	93,3	80,0	86,7	80,0	60,0	53,3	30,0	73,3	73,3	66,7	83,3	73,3	53,3	36,7	93,3	100,0	56,7	86,7	56,7	70,0	46,7	76,7	26,7	73,3	33,3	66,7
25	70,0	90,0	76,7	86,7	80,0	56,7	43,3	30,0	73,3	73,3	66,7	86,7	73,3	50,0	36,7	80,0	96,7	53,3	83,3	53,3	66,7	40,0	73,3	20,0	73,3	33,3	64,1
26	70,0	93,3	80,0	86,7	86,7	60,0	36,7	26,7	76,7	73,3	63,3	86,7	73,3	56,7	33,3	80,0	96,7	53,3	83,3	53,3	60,0	46,7	70,0	13,3	73,3	33,3	64,1
27	80,0	90,0	80,0	86,7	86,7	60,0	36,7	26,7	80,0	70,0	63,3	90,0	73,3	53,3	40,0	93,3	100,0	46,7	86,7	56,7	60,0	36,7	70,0	16,7	70,0	33,3	64,9
28	70,0	90,0	76,7	86,7	86,7	63,3	36,7	23,3	83,3	63,3	63,3	86,7	73,3	53,3	40,0	83,3	100,0	50,0	83,3	56,7	60,0	40,0	66,7	13,3	73,3	30,0	63,6
29	76,7	90,0	80,0	86,7	73,3	56,7	36,7	26,7	76,7	63,3	56,7	83,3	76,7	56,7	43,3	83,3	96,7	56,7	83,3	56,7	60,0	43,3	63,3	6,7	73,3	30,0	62,9
30	76,7	90,0	80,0	86,7	73,3	63,3	43,3	30,0	70,0	63,3	56,7	93,3	80,0	46,7	43,3	83,3	96,7	56,7	76,7	46,7	60,0	36,7	63,3	20,0	70,0	30,0	62,9
31	73,3	90,0	96,7	86,7	76,7	53,3	40,0	33,3	73,3	76,7	56,7	90,0	80,0	50,0	46,7	80,0	96,7	53,3	73,3	40,0	56,7	36,7	66,7	10,0	70,0	30,0	62,9
32	80,0	90,0	100,0	90,0	83,3	56,7	40,0	33,3	66,7	80,0	56,7	90,0	83,3	46,7	46,7	80,0	96,7	56,7	70,0	40,0	53,3	43,3	63,3	10,0	70,0	30,0	63,7
33	70,0	93,3	100,0	90,0	86,7	60,0	36,7	33,3	70,0	73,3	56,7	90,0	83,3	46,7	50,0	80,0	93,3	60,0	70,0	43,3	43,3	43,3	66,7	13,3	76,7	23,3	63,6
34	70,0	93,3	100,0	86,7	86,7	60,0	40,0	33,3	66,7	80,0	63,3	93,3	83,3	60,0	50,0	80,0	93,3	60,0	70,0	43,3	50,0	36,7	73,3	16,7	73,3	23,3	64,9
35	73,3	93,3	90,0	90,0	73,3	60,0	36,7	33,3	66,7	80,0	60,0	86,7	80,0	60,0	53,3	80,0	93,3	66,7	70,0	56,7	63,3	40,0	76,7	16,7	73,3	23,3	65,3
36	73,3	93,3	96,7	90,0	73,3	66,7	36,7	23,3	66,7	83,3	66,7	90,0	83,3	63,3	53,3	80,0	93,3	63,3	70,0	56,7	60,0	40,0	70,0	20,0	70,0	23,3	65,6
37	73,3	90,0	96,7	86,7	73,3	73,3	33,3	20,0	66,7	83,3	66,7	86,7	83,3	56,7	53,3	80,0	93,3	60,0	70,0	53,3	60,0	36,7	73,3	23,3	66,7	23,3	64,7
38	73,3	90,0	93,3	93,3	70,0	63,3	30,0	23,3	66,7	83,3	66,7	86,7	86,7	66,7	53,3	80,0	90,0	66,7	70,0	53,3	60,0	36,7	76,7	20,0	70,0	23,3	65,1
39	73,3	90,0	93,3	96,7	83,3	63,3	26,7	23,3	66,7	80,0	63,3	86,7	83,3	70,0	53,3	80,0	90,0	70,0	66,7	53,3	60,0	33,3	80,0	20,0	66,7	23,3	65,3
40	73,3	90,0	93,3	86,7	83,3	63,3	33,3	23,3	63,3	80,0	63,3	90,0	83,3	70,0	53,3	80,0	90,0	70,0	70,0	53,3	63,3	33,3	80,0	16,7	66,7	23,3	65,3
41	73,3	90,0	90,0	93,3	76,7	66,7	36,7	23,3	66,7	80,0	60,0	90,0	86,7	63,3	53,3	76,7	90,0	70,0	66,7	53,3	70,0	33,3	80,0	13,3	66,7	23,3	65,1
42	73,3	86,7	90,0	93,3	73,3	70,0	43,3	26,7	66,7	80,0	60,0	90,0	83,3	63,3	43,3	80,0	90,0	70,0	63,3	53,3	66,7	33,3	73,3	16,7	73,3	23,3	64,9
43	73,3	86,7	90,0	90,0	73,3	70,0	43,3	23,3	63,3	76,7	66,7	80,0	86,7	63,3	43,3	83,3	90,0	70,0	66,7	53,3	66,7	33,3	73,3	23,3	76,7	23,3	65,0
44	76,7	90,0	86,7	90,0	70,0	63,3	43,3	16,7	63,3	76,7	63,3	80,0	86,7	60,0	40,0	83,3	90,0	70,0	66,7	53,3	70,0	36,7	73,3	23,3	66,7	23,3	64,0
45	76,7	90,0	86,7	90,0	76,7	60,0	33,3	20,0	63,3	73,3	53,3	83,3	83,3	60,0	40,0	86,7	90,0	63,3	66,7	53,3	70,0	40,0	76,7	20,0	66,7	23,3	63,3
46	76,7	90,0	90,0	86,7	76,7	63,3	40,0	23,3	60,0	80,0	56,7	80,0	83,3	63,3	40,0	86,7	90,0	66,7	60,0	50,0	70,0	43,3	76,7	16,7	70,0	23,3	64,0
47	76,7	90,0	93,3	83,3	73,3	66,7	46,7	30,0	60,0	76,7	56,7	80,0	83,3	60,0	33,3	90,0	90,0	70,0	53,3	46,7	73,3	43,3	76,7	23,3	66,7	26,7	64,2
48	76,7	90,0	93,3	83,3	70,0	63,3	46,7	30,0	60,0	80,0	53,3	80,0	83,3	66,7	33,3	90,0	93,3	66,7	53,3	46,7	73,3	43,3	73,3	23,3	66,7	23,3	64,0
49	76,7	90,0	93,3	83,3	63,3	60,0	46,7	30,0	60,0	80,0	53,3	83,3	83,3	60,0	40,0	86,7	93,3	70,0	56,7	43,3	70,0	40,0	73,3	23,3	73,3	23,3	63,7
50	76,7	90,0	93,3	83,3	63,3	63,3	46,7	23,3	60,0	83,3	60,0	80,0	83,3	63,3	40,0	80,0	96,7	70,0	56,7	43,3	63,3	36,7	70,0	16,7	76,7	23,3	63,2
Avg.	72,2	89,1	87,1	92,7	75,4	59,1	48,1	29,7	72,0	74,5	59,0	78,9	76,3	55,5	37,9	84,4	88,1	54,5	75,1	47,0	61,3	42,3	69,1	23,7	67,5	34,1	

Table A.3 Average of accuracies, according to the filter, obtained for user 2

Filter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
None	**84,5**	**97,8**	**89,1**	**100,0**	**84,9**	**80,2**	**49,6**	**31,7**	**85,2**	**72,1**	**75,5**	**88,6**	**79,3**	**88,1**	**59,6**	**100,0**	**90,7**	**63,9**	**80,6**	**58,7**	**65,4**	**44,2**	**86,3**	**17,1**	**65,2**	**46,6**	**72,5**
And	**81,5**	**94,0**	**92,6**	**91,2**	**93,2**	**65,9**	**58,3**	**27,4**	**87,3**	**83,0**	**68,7**	**83,4**	**92,8**	**60,4**	**51,3**	**85,7**	**89,2**	**64,6**	**77,4**	**51,7**	**61,8**	**48,7**	**83,5**	**16,1**	**75,7**	**34,0**	**70,0**
Or	61,2	71,1	79,3	93,9	63,7	47,8	58,3	24,3	64,0	62,3	30,4	66,0	23,8	33,0	16,4	61,0	80,6	34,8	78,9	26,4	37,7	56,3	36,4	27,0	42,1	30,8	50,3
Kinect	46,4	83,7	80,3	89,6	52,0	27,5	26,8	25,5	54,3	81,0	49,3	72,3	95,7	44,2	24,9	82,6	96,7	60,5	75,3	62,3	68,1	38,5	77,6	28,1	91,6	27,6	60,1
Library	**86,4**	**98,5**	**84,3**	**96,7**	**86,2**	**76,7**	**60,6**	**35,3**	**86,5**	**74,5**	**64,8**	**77,9**	**87,4**	**80,0**	**39,8**	**92,9**	**84,2**	**50,5**	**77,1**	**31,7**	**62,6**	**34,4**	**73,3**	**25,4**	**59,9**	**35,8**	**67,8**
Avg.	72,0	89,0	85,1	94,3	76,0	59,6	50,7	28,8	75,5	74,6	57,7	77,6	75,8	61,2	38,4	84,4	88,3	54,9	77,9	46,2	59,1	44,4	71,4	22,7	66,9	35,0	

Table A.4 Average of accuracies, according to the hand variation, obtained for user 2

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
1	92,9	93,2	87,4	93,0	63,2	53,7	71,7	33,7	45,3	82,6	72,3	10,9	68,8	31,3	46,8	64,9	97,5	28,8	64,5	33,3	59,0	48,2	45,1	21,5	36,5	45,3	57,4
2	77,7	89,5	84,4	70,6	68,3	54,4	70,8	48,5	57,0	66,5	57,4	38,9	68,8	70,8	28,9	54,6	49,6	30,8	90,6	31,3	49,8	50,5	58,5	40,2	52,2	46,5	58,0
3	100,0	98,2	98,3	96,2	69,2	51,3	58,4	44,0	36,1	29,8	49,2	42,4	74,6	48,3	31,7	55,4	77,8	34,9	77,3	29,1	50,1	61,2	57,6	40,7	65,8	43,6	58,5
4	83,4	98,3	95,7	85,3	60,0	54,1	63,6	49,4	73,7	66,6	59,8	60,6	70,2	36,3	24,2	44,3	75,3	43,0	85,0	30,6	66,0	62,5	67,2	38,5	55,5	49,6	61,5
5	87,9	82,0	94,4	100,0	59,0	76,7	57,1	48,1	78,6	65,2	46,1	67,3	66,0	39,3	16,1	81,7	67,9	44,3	77,8	29,0	64,9	66,0	62,3	32,4	52,8	62,9	62,5
6	79,2	87,7	76,6	94,7	70,0	59,7	66,2	34,8	52,0	54,8	48,7	72,4	67,8	43,7	31,7	80,1	81,2	40,9	81,5	29,8	89,0	91,5	69,0	47,1	67,2	46,8	64,0
7	62,2	98,0	83,9	98,0	88,5	96,3	57,5	22,1	92,4	62,6	78,0	74,9	62,0	42,1	28,4	94,4	82,8	34,0	87,0	44,2	45,4	76,1	73,6	47,7	51,7	59,4	67,0
8	85,9	94,3	90,2	98,2	72,5	53,5	52,7	78,8	79,8	71,8	56,2	76,5	80,7	62,3	54,4	85,7	90,4	41,0	90,2	47,7	54,7	38,0	69,1	44,9	97,2	56,4	70,1
9	73,5	87,5	91,3	100,0	97,8	62,0	52,4	32,3	59,9	85,0	45,6	92,6	76,5	49,3	37,4	98,0	86,1	52,3	79,9	77,7	60,6	81,7	59,4	56,6	73,1	43,4	69,7
10	**87,0**	**88,0**	**90,3**	**95,5**	**92,8**	**87,9**	**65,0**	**24,3**	**65,8**	**79,9**	**36,4**	**83,3**	**73,6**	**51,7**	**29,5**	**94,4**	**84,3**	**86,2**	**91,1**	**51,9**	**95,4**	**54,6**	**47,2**	**69,7**	**98,2**	**45,3**	**71,9**
11	**91,1**	**90,4**	**90,3**	**97,1**	**73,0**	**54,3**	**58,3**	**26,7**	**98,6**	**79,6**	**34,5**	**86,0**	**96,9**	**82,1**	**52,7**	**91,8**	**89,9**	**43,8**	**89,3**	**46,3**	**78,9**	**87,4**	**59,1**	**44,2**	**65,5**	**76,5**	**72,5**
12	58,4	98,6	85,9	100,0	81,6	67,8	56,4	66,1	78,5	90,7	57,4	57,7	84,2	59,5	33,3	96,7	81,8	77,2	92,3	76,8	92,8	45,9	62,2	31,9	75,0	39,3	71,1
13	81,7	89,1	73,0	99,8	84,8	49,7	53,9	32,5	81,5	89,2	59,5	62,8	70,7	43,8	45,2	100,0	75,0	68,7	93,0	36,1	54,4	55,9	98,6	43,7	88,2	51,6	68,6
14	95,4	98,5	70,0	99,8	81,2	59,9	95,7	18,7	91,5	83,0	76,1	71,0	79,1	67,9	29,0	95,1	84,3	58,5	89,0	37,5	54,2	64,1	61,1	30,9	55,1	34,6	68,5
15	65,7	95,3	86,7	100,0	78,9	44,7	82,9	55,5	98,5	69,6	67,4	78,3	74,2	68,0	39,7	100,0	56,1	73,5	86,3	63,3	54,5	63,2	45,3	23,0	89,3	71,2	70,4
16	**99,6**	**96,2**	**88,9**	**97,8**	**87,2**	**58,4**	**54,6**	**37,0**	**94,3**	**77,9**	**56,4**	**85,5**	**82,7**	**71,6**	**55,6**	**98,9**	**94,7**	**74,8**	**72,6**	**45,2**	**83,3**	**32,6**	**75,1**	**62,1**	**66,9**	**55,6**	**73,3**
17	72,7	98,9	83,8	99,2	91,6	63,9	68,3	38,8	90,7	78,1	55,6	84,3	81,7	61,4	26,2	97,7	96,0	48,7	78,2	48,6	61,5	50,8	65,4	40,9	71,7	37,9	68,9
18	77,3	100,0	91,2	100,0	98,0	67,7	58,7	37,2	87,3	76,2	70,3	91,6	65,4	60,0	30,7	100,0	93,1	48,9	80,6	56,8	55,0	30,0	75,3	34,2	69,2	36,1	68,9
19	76,6	100,0	85,4	99,3	80,8	57,4	63,2	51,5	91,5	77,5	55,1	90,8	74,1	59,0	29,3	100,0	100,0	51,9	75,9	81,6	75,9	35,9	76,3	32,6	76,1	33,3	70,4
20	71,0	54,7	84,6	100,0	80,7	55,4	55,8	37,4	91,9	82,7	75,3	76,6	71,8	48,8	29,6	95,5	100,0	64,4	84,1	51,6	72,6	36,2	72,7	34,0	70,7	35,2	66,7
21	64,0	94,6	85,3	100,0	71,1	55,5	52,0	25,1	78,3	62,4	69,1	87,2	68,8	28,7	26,4	94,4	97,3	64,8	84,8	58,6	64,5	50,9	84,1	26,6	69,5	33,1	65,3
22	65,1	90,4	82,3	94,7	70,0	59,9	56,3	25,7	71,6	84,1	67,3	77,0	72,7	47,1	38,3	97,7	95,6	57,2	79,3	53,8	63,7	78,4	73,5	16,0	67,3	32,2	66,0
23	68,4	96,9	79,5	94,3	83,4	62,1	54,4	27,0	68,9	81,1	67,2	80,0	74,8	48,9	39,3	92,0	100,0	50,1	87,5	54,8	67,7	49,9	72,7	22,4	75,6	34,1	66,7
24	74,2	91,4	83,9	86,1	82,1	56,3	48,6	30,2	74,4	68,3	70,9	84,1	69,3	76,3	39,7	91,4	100,0	56,5	85,0	55,7	74,3	41,9	78,9	27,3	94,2	35,1	68,3
25	69,1	90,7	82,9	91,5	96,8	81,1	46,5	34,2	83,5	69,6	69,5	87,8	72,9	47,5	41,4	80,2	99,5	68,5	81,7	76,4	70,5	37,4	82,8	23,0	79,1	33,5	69,1
26	72,6	97,0	75,6	90,6	87,7	81,4	39,1	65,9	83,1	74,8	73,9	98,1	75,5	60,1	35,9	82,4	99,0	48,9	84,7	53,9	72,8	45,9	67,0	14,7	72,0	34,8	68,8
27	**84,5**	**97,6**	**78,0**	**87,2**	**90,4**	**57,2**	**46,3**	**31,8**	**82,4**	**93,5**	**76,9**	**99,9**	**86,4**	**73,1**	**63,2**	**98,3**	**96,7**	**48,1**	**87,4**	**86,0**	**86,1**	**40,2**	**69,2**	**22,6**	**71,3**	**91,8**	**74,9**

28	71,0	90,5	72,0	91,5	88,8	64,1	37,4	18,6	83,9	59,3	99,4	91,6	92,9	53,2	35,6	96,7	100,0	46,7	79,2	57,3	88,9	42,2	68,7	35,3	70,5	31,3	68,0
29	80,3	85,6	84,5	85,8	73,5	54,8	34,3	29,8	75,4	64,3	60,1	87,4	74,0	61,3	50,0	83,4	96,9	54,4	87,3	56,0	98,2	38,7	67,9	16,1	68,4	69,3	66,8
30	80,2	86,4	85,8	91,3	74,0	64,4	74,3	38,5	84,9	67,3	57,4	95,4	84,4	44,5	41,2	83,9	97,2	61,6	81,6	51,1	59,9	36,3	63,2	23,2	92,5	32,9	67,4
31	75,8	88,5	95,0	91,5	76,6	52,8	41,0	38,1	75,9	75,0	52,0	91,4	78,5	48,7	84,6	81,1	95,3	53,3	74,7	36,3	88,7	40,5	63,5	14,3	69,6	32,8	66,0
32	78,7	88,7	100,0	91,0	87,0	56,5	37,1	33,0	69,1	79,9	53,4	87,9	97,4	42,6	47,6	79,7	92,4	56,0	68,8	35,8	51,8	47,5	67,0	13,9	71,7	51,8	64,9
33	71,9	92,0	95,5	91,4	87,5	60,0	57,4	29,2	70,0	72,2	57,7	90,1	89,5	72,9	46,3	78,8	93,5	56,2	65,8	47,8	45,2	41,3	66,3	16,5	73,1	23,0	65,1
34	73,4	92,9	97,5	89,3	85,0	60,5	37,7	34,0	65,4	78,3	66,8	95,4	86,1	80,0	75,2	82,5	89,2	91,9	67,9	47,5	53,8	66,5	71,8	18,4	69,6	20,4	69,1
35	69,8	97,3	94,6	99,9	70,2	55,9	38,4	37,6	63,2	82,5	56,4	90,8	76,3	59,6	70,6	77,9	97,9	71,4	70,3	57,2	60,2	44,2	75,8	13,4	98,8	21,2	67,4
36	75,9	90,7	99,9	85,9	76,2	65,8	31,8	50,2	63,0	80,0	97,6	86,1	83,7	67,4	56,8	76,5	95,1	61,0	67,0	61,6	62,5	62,3	69,2	22,5	67,4	24,6	68,5
37	74,3	91,0	97,5	84,3	69,5	74,3	38,1	24,5	69,7	82,5	77,6	93,0	87,9	61,1	58,8	76,6	92,1	62,1	72,3	48,5	59,8	35,9	86,0	46,1	65,9	26,2	67,5
38	73,6	90,1	97,5	98,1	68,1	68,5	34,2	22,4	67,0	85,1	70,5	85,0	90,0	67,1	52,9	81,8	95,2	67,0	66,2	57,3	57,8	33,2	73,0	56,1	74,4	26,3	67,6
39	69,5	94,9	98,3	95,8	78,5	63,2	32,7	54,5	91,5	86,4	63,2	84,7	78,9	74,8	51,3	81,6	96,7	87,9	70,2	53,9	63,6	31,6	76,7	20,7	70,7	43,9	69,8
40	70,8	93,4	98,0	95,7	90,4	81,7	35,4	34,3	64,9	82,7	63,1	94,9	81,6	75,1	52,7	77,3	89,0	94,6	69,3	52,8	92,9	31,4	80,4	17,2	64,1	38,5	70,1
41	**68,3**	**92,5**	**91,3**	**94,1**	**81,5**	**76,4**	**33,4**	**22,2**	**74,3**	**93,4**	**86,9**	**97,4**	**84,5**	**61,2**	**78,9**	**89,1**	**89,0**	**68,4**	**71,1**	**88,1**	**92,5**	**29,0**	**77,2**	**38,3**	**63,6**	**25,0**	**71,8**
42	71,7	86,0	93,1	97,8	74,9	69,2	80,1	26,1	82,0	84,5	86,5	85,0	97,5	64,9	45,5	92,6	98,4	68,4	61,3	49,7	70,4	35,7	69,2	14,1	73,1	42,8	70,0
43	77,1	91,3	88,0	88,5	68,8	90,9	45,4	19,2	62,5	73,9	91,1	83,9	88,4	60,3	42,8	86,4	91,1	69,3	71,5	49,6	75,4	35,2	78,5	25,5	72,3	24,0	67,4
44	75,3	87,5	82,0	96,7	63,6	70,7	71,9	12,8	75,0	82,0	70,9	80,2	83,7	58,5	49,3	85,6	86,8	74,1	70,6	79,2	70,4	39,5	99,3	39,5	63,3	41,7	69,6
45	80,7	93,8	95,3	92,1	74,8	57,0	61,0	22,5	67,4	73,3	57,4	81,8	87,4	62,9	44,3	84,3	95,8	66,0	70,4	51,8	91,2	37,7	74,8	20,5	80,4	24,3	67,3
46	81,3	86,4	90,8	85,0	73,6	63,8	42,3	47,3	58,7	98,4	60,2	83,6	88,2	96,2	69,3	88,6	92,8	90,2	61,0	51,3	74,8	48,2	79,7	21,1	75,3	19,2	70,3
47	75,7	86,0	94,7	81,8	68,4	66,2	49,8	29,5	66,0	75,7	92,0	88,3	88,9	56,0	46,8	89,6	88,5	78,4	58,0	46,0	72,9	41,5	75,6	24,3	92,5	29,0	67,8
48	80,7	90,3	96,8	88,3	89,5	59,6	47,9	28,4	62,6	76,3	58,8	81,3	84,1	85,2	42,8	98,9	95,3	66,4	74,9	50,7	78,1	45,3	74,0	25,4	84,1	29,5	69,1
49	79,7	94,5	91,3	79,7	66,6	62,4	49,3	45,4	85,8	75,4	57,9	82,3	84,4	96,3	35,9	90,7	94,1	83,1	59,6	46,2	89,6	48,0	81,2	20,1	78,4	50,5	70,3
50	82,0	95,0	91,7	98,0	71,8	93,8	50,2	63,7	85,4	87,8	57,9	84,8	83,9	62,8	43,2	79,4	100,0	71,4	53,6	43,2	92,4	39,6	75,8	16,2	80,9	27,9	70,5
Avg.	77,1	91,6	88,6	93,2	78,4	64,3	53,3	36,4	75,0	76,4	64,9	80,8	79,6	59,8	44,1	86,2	90,3	60,8	77,0	52,1	70,2	48,6	70,9	30,6	72,6	40,4	

Table A.5 Average of accuracies, according to the filter, obtained for user 3

Filter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
None	**83,8**	**97,8**	**91,6**	**100,0**	**85,6**	**77,4**	**52,6**	**31,9**	**81,5**	**72,7**	**77,8**	**91,0**	**79,7**	**90,1**	**57,4**	**95,7**	**100,0**	**61,2**	**76,1**	**56,1**	**73,6**	**46,2**	**81,2**	**25,0**	**65,6**	**39,4**	**72,7**
And	**85,3**	**97,0**	**88,0**	**97,9**	**83,8**	**67,6**	**50,4**	**33,8**	**86,7**	**85,3**	**67,6**	**92,2**	**94,0**	**60,1**	**48,6**	**85,8**	**96,0**	**66,0**	**77,9**	**56,5**	**66,8**	**54,6**	**86,1**	**20,3**	**74,6**	**33,9**	**71,4**
Or	63,6	73,3	81,3	95,6	74,3	47,4	47,8	28,6	62,4	67,4	69,6	70,0	27,4	24,5	21,5	76,4	76,5	46,9	74,0	58,7	40,0	36,3	49,0	28,7	45,7	38,9	54,8
Kinect	43,7	90,8	82,4	82,0	53,8	25,7	32,6	26,3	50,3	82,7	42,3	70,7	95,4	41,4	28,2	86,1	94,8	58,3	72,0	64,6	62,0	39,4	78,9	34,9	92,8	9,0	59,3
Library	**79,7**	**97,7**	**91,3**	**99,1**	**86,7**	**94,4**	**75,2**	**37,0**	**83,3**	**76,0**	**68,4**	**83,4**	**85,7**	**61,6**	**39,0**	**88,4**	**82,8**	**51,3**	**82,5**	**28,2**	**70,9**	**40,5**	**66,7**	**21,8**	**53,5**	**35,2**	**68,5**
Avg.	71,2	91,3	86,9	94,9	76,8	62,5	51,7	31,5	72,8	76,8	65,1	81,4	76,5	55,5	38,9	86,5	90,0	56,7	76,5	52,8	62,7	43,4	72,4	26,1	66,4	31,3	

Table A.6 Average of accuracies, according to the hand variation, obtained for user 3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
1	92,3	96,9	84,6	95,1	64,3	54,6	66,8	37,4	52,6	84,3	72,6	7,3	70,2	27,1	50,4	55,6	77,0	24,5	63,1	35,5	59,3	52,8	55,7	17,9	35,8	54,8	57,2
2	82,9	94,4	94,5	94,1	65,4	54,7	70,0	48,0	30,3	65,2	55,8	36,5	76,2	65,8	28,9	51,7	85,4	36,1	86,9	34,3	55,3	51,8	63,7	38,2	52,9	22,8	59,3
3	95,6	96,8	90,2	99,7	78,6	57,4	61,8	50,5	40,1	60,2	52,3	45,7	68,8	42,4	23,3	54,8	80,9	38,1	78,7	37,5	53,1	62,5	58,6	46,9	58,9	38,9	60,5
4	82,0	100,0	99,8	84,2	65,7	60,5	66,1	47,9	68,4	69,4	63,2	58,8	72,2	47,8	26,8	44,4	71,0	44,6	86,0	29,9	66,9	61,7	64,8	38,7	56,2	49,4	62,6
5	91,4	84,4	91,3	100,0	64,7	53,7	58,6	42,9	80,9	67,7	45,8	68,4	67,2	45,9	20,7	78,9	68,6	45,5	83,2	28,9	57,2	64,1	71,2	39,5	54,4	62,9	63,0
6	79,2	60,7	76,6	97,8	69,5	61,3	60,8	71,9	79,6	47,2	43,4	75,9	65,6	48,3	28,4	74,8	77,9	38,8	78,7	47,9	62,0	64,6	71,7	62,4	67,1	47,7	63,8
7	64,5	64,1	84,6	99,5	81,4	67,2	60,3	25,1	73,4	61,1	66,3	76,3	69,6	40,5	57,4	94,1	77,7	38,0	84,3	38,8	51,2	52,9	81,2	47,5	54,5	55,7	64,1
8	74,3	92,2	83,8	100,0	75,2	56,2	51,5	32,1	90,3	69,2	49,5	72,9	99,6	50,4	48,1	94,7	81,3	40,9	83,8	43,1	76,1	41,2	76,0	32,0	71,3	54,3	66,9
9	38,9	96,4	84,4	100,0	76,2	52,1	49,7	48,8	73,8	89,0	44,9	77,1	82,7	55,7	52,1	99,4	83,4	62,7	88,6	55,0	58,8	77,1	59,5	33,6	66,6	58,8	67,9
10	76,0	92,7	79,9	99,3	74,1	95,6	56,4	20,5	65,5	77,0	54,9	89,0	71,9	50,6	61,0	95,2	96,8	58,2	99,8	54,0	96,3	49,1	63,5	30,1	77,9	47,7	70,5
11	**90,3**	**91,1**	**87,0**	**98,8**	**71,6**	**64,4**	**62,0**	**43,5**	**79,1**	**77,3**	**42,5**	**84,7**	**84,7**	**53,2**	**33,3**	**94,6**	**68,1**	**41,9**	**99,3**	**55,7**	**90,3**	**72,3**	**56,4**	**61,7**	**86,8**	**77,0**	**71,8**
12	94,7	91,8	82,5	100,0	98,5	40,4	55,9	25,4	99,6	71,4	52,8	64,6	70,7	82,6	27,2	96,8	96,2	77,4	85,5	44,9	75,0	56,2	77,0	56,6	84,5	31,7	70,8
13	**80,0**	**82,6**	**97,2**	**98,5**	**73,5**	**48,3**	**85,5**	**49,6**	**81,8**	**60,1**	**75,0**	**98,9**	**70,7**	**52,7**	**50,6**	**98,9**	**98,3**	**73,3**	**85,5**	**47,2**	**96,2**	**35,9**	**88,9**	**23,9**	**82,3**	**83,7**	**73,8**
14	92,7	99,9	89,7	98,8	93,0	47,1	54,7	17,0	89,7	90,5	84,5	98,5	78,9	81,9	36,0	99,7	66,1	40,7	78,7	61,5	81,3	30,1	51,3	71,6	75,0	58,4	71,8
15	63,9	96,7	88,7	98,6	85,6	46,3	89,8	30,8	93,0	74,3	99,6	98,2	72,4	77,5	36,3	94,9	68,3	56,5	87,6	42,2	65,0	38,9	44,2	27,9	54,3	52,5	68,6
16	**70,1**	**94,3**	**88,7**	**100,0**	**95,5**	**65,5**	**56,0**	**29,9**	**91,2**	**77,1**	**66,8**	**80,4**	**83,8**	**93,3**	**41,5**	**95,7**	**90,7**	**78,3**	**73,1**	**79,3**	**50,3**	**62,9**	**63,8**	**64,2**	**90,8**	**45,8**	**74,2**
17	77,5	97,1	89,4	100,0	84,3	58,2	61,7	35,1	95,5	84,8	57,6	81,6	71,0	55,7	27,2	94,2	89,5	55,8	79,1	52,5	60,1	77,4	64,5	34,7	67,6	33,7	68,7
18	75,9	100,0	91,2	96,7	97,0	58,6	64,1	44,4	91,7	84,9	70,6	86,1	71,9	59,1	28,1	97,5	98,2	52,7	77,7	58,3	71,0	52,5	81,5	33,6	77,1	37,7	71,5
19	80,7	100,0	91,3	96,3	76,5	58,3	57,9	43,0	86,4	75,9	64,5	83,2	68,5	63,7	31,2	96,2	98,4	48,1	83,3	61,5	76,2	33,9	80,0	72,3	80,5	59,0	71,8
20	69,9	96,1	79,6	98,2	81,3	33,3	64,4	40,1	49,3	84,9	70,5	73,1	72,5	48,3	33,1	88,8	100,0	30,3	82,6	52,9	76,5	46,8	72,1	26,5	50,8	8,8	62,7
21	55,7	69,8	86,1	98,5	69,6	21,4	57,1	31,7	48,8	75,8	77,6	89,3	74,7	58,3	27,2	98,7	100,0	64,0	77,7	55,1	71,3	46,7	87,3	22,9	73,1	36,1	64,4
22	63,0	91,6	86,3	89,6	73,2	56,6	53,6	27,3	78,0	77,0	69,1	81,3	71,5	46,1	33,4	100,0	96,0	53,1	76,1	59,9	67,9	47,4	75,4	17,3	65,9	37,5	65,2
23	71,0	95,1	85,0	99,6	81,7	59,9	55,9	50,6	77,3	83,1	59,0	78,5	71,2	48,7	39,8	94,6	97,8	53,7	87,4	52,9	62,8	46,9	73,9	24,4	77,8	37,9	67,9
24	69,1	90,6	81,8	83,5	75,3	59,0	51,9	32,6	70,9	74,9	63,6	85,3	72,5	53,6	37,0	91,2	87,7	55,7	87,2	59,8	72,1	44,1	81,5	27,0	74,2	33,9	66,0
25	76,3	91,4	91,8	91,7	77,3	92,1	48,1	26,3	99,1	71,0	82,0	89,5	70,4	46,8	34,4	84,0	95,6	49,3	91,4	51,5	66,9	39,1	76,7	20,6	71,3	50,9	68,7
26	66,2	93,1	84,5	88,7	93,0	82,1	35,6	60,3	92,8	72,8	62,7	85,2	70,0	59,3	36,9	79,9	96,0	51,2	85,2	84,9	59,5	43,9	73,9	50,2	78,3	33,7	70,0
27	**77,9**	**90,7**	**79,9**	**89,1**	**85,0**	**64,6**	**66,5**	**71,1**	**82,9**	**72,8**	**90,6**	**94,0**	**73,4**	**56,1**	**78,8**	**89,0**	**98,1**	**64,6**	**98,9**	**52,4**	**62,9**	**32,5**	**99,1**	**20,3**	**72,7**	**30,8**	**72,9**

28	69,4	94,0	77,6	82,7	90,9	67,1	73,0	26,6	79,2	58,5	61,9	86,5	70,0	54,3	38,9	87,5	99,4	49,2	88,1	59,8	61,6	40,3	64,2	15,7	73,8	25,6	65,2
29	91,3	92,4	94,9	88,2	71,0	54,6	38,9	27,9	76,7	67,2	84,2	82,8	74,2	56,9	65,7	82,1	92,8	54,7	86,7	56,7	55,8	47,6	63,7	11,3	73,0	44,8	66,8
30	72,6	87,4	79,7	97,3	92,5	65,7	63,1	27,1	69,6	59,4	81,9	94,9	76,2	46,4	44,9	87,2	100,0	55,0	81,3	45,1	57,4	36,9	60,0	17,2	66,3	25,7	65,0
31	98,8	91,6	96,0	85,4	75,2	67,1	45,1	33,7	76,2	76,4	81,4	94,8	80,2	48,2	47,1	76,0	99,4	56,2	76,3	37,3	58,9	41,6	90,9	12,8	70,4	30,3	67,2
32	86,8	91,6	100,0	87,9	86,4	61,2	37,6	33,7	71,2	81,8	60,7	94,6	78,7	45,6	47,8	81,6	100,0	59,7	71,4	41,8	73,5	46,9	62,0	14,3	87,8	69,5	68,2
33	72,1	90,5	100,0	89,0	87,0	63,9	41,1	34,0	69,5	73,4	57,8	89,6	86,8	79,5	50,8	80,2	88,9	62,4	92,7	58,0	43,9	71,6	80,3	17,7	74,7	19,6	68,3
34	97,6	92,1	98,5	85,5	81,7	72,9	43,5	37,2	63,8	84,8	60,9	90,8	82,4	64,2	49,0	78,0	95,9	57,0	68,5	45,1	53,6	34,3	81,0	15,3	74,2	27,2	66,7
35	72,3	98,5	89,6	87,0	89,8	59,4	37,6	42,8	66,1	83,5	62,5	86,2	84,5	62,8	53,0	78,5	95,2	64,3	72,4	93,1	65,8	39,3	76,9	12,3	75,4	25,8	68,3
36	72,3	95,4	98,3	93,6	71,5	90,4	41,0	24,0	67,7	77,8	64,9	85,3	84,2	58,4	56,1	80,8	94,4	58,6	68,0	57,0	59,8	38,6	67,0	59,8	71,3	19,2	67,5
37	76,5	89,5	99,4	88,3	75,0	70,9	59,8	57,9	95,2	78,7	68,5	87,8	82,3	59,3	56,8	78,8	93,6	70,6	70,7	59,5	61,6	41,8	77,0	27,0	70,0	62,1	71,5
38	84,8	95,7	96,5	96,2	65,6	67,4	28,1	26,7	68,7	90,0	69,4	83,3	86,5	67,5	56,8	82,6	88,7	65,7	67,5	57,2	59,6	37,1	73,7	16,0	72,1	36,8	66,9
39	**77,4**	**86,8**	**98,2**	**95,1**	**86,9**	**61,5**	**65,4**	**63,0**	**66,2**	**83,8**	**67,4**	**95,7**	**83,3**	**75,1**	**80,2**	**80,0**	**94,6**	**68,4**	**75,2**	**61,1**	**61,3**	**31,2**	**78,9**	**57,2**	**68,4**	**42,5**	**73,3**
40	75,7	86,8	94,6	95,0	88,8	67,3	35,6	21,2	61,2	84,7	98,2	89,1	83,7	68,4	54,7	81,7	93,2	74,4	67,5	50,9	96,4	30,3	80,7	28,4	66,1	20,6	69,0
41	74,5	92,8	90,8	90,5	72,5	68,6	33,6	22,5	67,5	80,9	64,3	92,3	82,4	64,9	78,9	79,8	92,1	73,2	63,9	53,2	71,7	37,3	84,8	15,3	68,4	29,7	67,2
42	71,4	85,8	92,8	95,3	72,6	86,4	40,4	29,9	64,1	85,8	56,4	94,6	100,0	60,7	45,4	82,4	86,5	71,8	66,3	70,2	97,2	36,0	77,1	46,3	91,8	22,4	70,4
43	96,5	91,5	91,1	87,0	93,7	71,4	42,4	40,6	84,3	81,9	78,2	79,2	83,4	89,8	43,6	88,7	87,2	75,4	70,3	51,0	69,3	36,1	74,0	45,0	81,0	23,8	71,4
44	79,1	94,4	85,3	87,4	70,3	74,8	44,7	20,1	84,0	77,4	68,3	90,5	91,0	65,2	40,4	79,7	93,2	84,9	64,8	86,2	71,9	31,9	74,2	19,2	72,2	26,0	68,3
45	74,6	88,2	85,7	94,0	80,8	60,1	38,1	21,1	80,0	73,2	54,8	99,8	87,2	64,9	38,0	84,1	93,5	67,9	69,8	57,8	91,5	43,9	79,6	44,1	77,1	58,6	69,6
46	75,0	93,9	89,2	83,4	77,9	63,1	39,9	18,5	59,9	84,2	52,9	81,2	82,3	63,3	44,7	82,1	88,1	82,3	55,3	84,5	66,0	42,1	84,4	18,4	73,9	19,5	65,6
47	75,8	94,0	99,0	83,9	78,0	64,1	44,3	36,4	60,6	77,9	98,6	80,6	85,6	57,4	35,1	88,7	91,4	68,5	88,1	43,2	84,8	81,5	74,0	56,0	62,6	29,7	70,8
48	84,2	85,6	91,7	84,7	70,4	62,2	44,9	33,1	57,5	83,8	80,2	84,1	90,5	82,7	36,7	91,3	91,0	84,9	55,4	48,5	70,0	46,3	73,3	31,7	97,0	22,9	68,6
49	81,0	88,4	88,6	85,7	88,1	61,3	41,7	38,7	73,0	77,8	84,5	86,0	83,6	55,7	50,9	81,8	94,9	72,4	79,9	43,0	76,6	40,6	90,3	41,0	76,9	27,2	69,6
50	73,7	89,9	94,0	88,1	62,1	72,0	51,1	36,5	63,9	85,4	60,1	84,3	88,3	58,8	42,8	81,4	98,9	70,4	59,5	46,4	98,5	34,1	77,0	34,3	87,1	21,7	67,7
Avg.	77,7	91,0	89,6	92,9	79,1	62,5	53,1	36,7	73,8	76,1	67,1	81,9	78,4	59,2	43,7	84,7	90,0	58,4	78,6	53,7	69,0	47,0	73,2	34,0	71,8	39,5	

Table A.7 Average of accuracies, according to the filter, obtained for user 4

Filter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
None	**81,1**	**100,0**	**89,6**	**100,0**	**80,6**	**82,6**	**52,2**	**31,0**	**77,1**	**68,8**	**81,7**	**99,5**	**83,5**	**80,7**	**57,0**	**99,0**	**92,3**	**59,1**	**77,6**	**61,9**	**69,1**	**45,1**	**80,3**	**18,1**	**66,4**	**40,4**	**72,1**
And	**84,8**	**98,1**	**90,7**	**97,8**	**82,0**	**72,3**	**54,9**	**32,5**	**87,7**	**94,3**	**64,5**	**81,5**	**92,5**	**67,1**	**49,9**	**89,2**	**97,2**	**69,5**	**71,1**	**52,0**	**61,4**	**54,7**	**85,9**	**22,1**	**79,6**	**29,3**	**71,6**
Or	62,3	86,9	79,0	90,4	67,9	40,8	42,6	35,6	71,0	62,8	27,3	70,1	22,9	24,3	53,2	72,7	68,3	45,8	72,2	46,3	39,7	41,0	47,6	29,1	59,3	52,1	54,3
Kinect	49,7	90,0	84,1	89,1	52,8	24,0	35,1	19,9	49,4	80,1	50,6	69,9	91,9	38,8	32,4	75,4	92,2	56,9	71,2	61,5	63,9	23,7	78,3	34,0	96,1	27,0	59,2
Library	**85,1**	**95,9**	**88,1**	**96,4**	**90,0**	**76,4**	**59,0**	**41,4**	**82,5**	**77,1**	**70,8**	**83,6**	**91,3**	**66,5**	**38,0**	**90,1**	**87,3**	**52,4**	**80,5**	**28,2**	**86,3**	**41,4**	**67,8**	**23,1**	**61,6**	**59,8**	**70,0**
Avg.	72,6	94,2	86,3	94,8	74,7	59,2	48,8	32,1	73,5	76,6	59,0	80,9	76,4	55,5	46,1	85,3	87,5	56,7	74,5	50,0	64,1	41,2	72,0	25,3	72,6	41,7	

Table A.8 Average of accuracies, according to the hand variation, obtained for user 4

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
1	91,8	95,8	87,7	91,9	59,3	54,4	68,5	32,9	54,3	78,9	75,1	5,9	74,5	25,4	48,7	62,5	74,8	27,7	65,1	29,4	56,1	51,8	47,8	15,6	35,3	46,3	56,1
2	91,4	86,6	87,6	85,7	51,4	48,1	74,4	44,3	61,7	63,5	51,2	41,6	43,4	63,9	32,8	47,9	87,8	30,7	87,9	32,3	51,3	51,4	56,3	36,2	50,9	46,2	57,9
3	98,6	95,9	92,2	95,7	71,1	48,9	65,0	47,0	76,5	63,3	48,3	29,7	76,5	46,5	22,7	51,0	76,6	33,7	80,0	32,4	50,3	64,0	58,4	45,0	62,1	50,3	60,8
4	83,5	97,0	92,0	86,0	62,0	59,0	62,8	49,3	75,2	64,8	61,8	63,8	71,8	36,3	28,5	48,9	75,8	46,1	86,8	26,0	68,5	63,2	65,6	35,7	57,7	48,0	62,2
5	90,7	81,7	96,8	100,0	56,2	52,9	61,9	44,0	75,7	62,1	49,4	69,3	65,0	51,1	15,4	93,2	67,3	47,3	77,8	29,2	63,7	58,9	63,1	38,1	51,7	61,9	62,5
6	79,4	64,9	74,4	100,0	66,6	56,7	64,3	44,9	86,3	52,6	81,5	74,1	67,9	46,9	23,8	80,3	80,6	42,6	86,7	33,6	95,4	70,1	71,5	45,0	68,5	50,9	65,8
7	68,3	59,0	82,1	97,5	61,7	73,3	56,4	23,6	77,5	64,4	63,3	73,4	69,2	40,5	30,3	88,7	76,6	62,1	77,6	37,7	52,3	77,4	75,7	48,9	54,8	59,4	63,5
8	71,4	71,4	88,8	100,0	60,3	58,4	57,8	31,6	76,8	71,5	55,0	85,1	91,4	51,2	21,9	84,5	81,9	48,1	81,0	46,2	51,4	56,0	65,1	37,1	64,5	87,2	65,2
9	45,0	96,4	86,3	100,0	75,5	75,0	54,9	28,2	80,9	79,3	39,9	90,9	87,2	68,4	49,3	94,2	88,5	37,3	90,6	85,3	56,9	62,3	64,8	39,1	81,7	70,8	70,3
10	**76,5**	**98,3**	**91,6**	**99,9**	**82,4**	**62,4**	**59,7**	**52,4**	**90,4**	**87,2**	**73,5**	**99,9**	**78,0**	**83,9**	**74,3**	**88,5**	**84,4**	**60,8**	**86,1**	**59,2**	**96,7**	**66,7**	**59,2**	**37,4**	**70,4**	**50,1**	**75,8**
11	63,8	89,4	83,2	100,0	67,2	96,9	50,8	96,0	92,2	71,8	65,8	85,1	69,9	47,3	63,0	97,9	69,0	41,2	78,4	49,5	50,8	61,1	60,1	21,5	70,3	48,8	68,9
12	**97,7**	**91,7**	**85,5**	**99,1**	**99,1**	**53,7**	**51,0**	**69,8**	**87,2**	**81,2**	**86,7**	**66,2**	**70,3**	**98,5**	**26,3**	**98,9**	**70,9**	**94,9**	**87,8**	**81,1**	**63,3**	**40,6**	**75,5**	**49,8**	**59,8**	**39,4**	**74,1**
13	**89,8**	**92,3**	**73,8**	**100,0**	**93,0**	**83,2**	**94,0**	**17,7**	**75,9**	**65,2**	**80,9**	**66,5**	**80,1**	**74,5**	**26,6**	**98,8**	**70,0**	**74,3**	**93,7**	**39,3**	**83,3**	**57,1**	**97,1**	**38,6**	**95,3**	**34,1**	**72,9**
14	90,3	87,8	70,9	98,3	96,9	55,7	73,9	24,3	80,5	92,1	86,9	83,6	74,2	66,6	49,6	99,9	99,0	43,4	90,4	33,9	72,3	46,0	67,5	23,7	58,9	86,4	71,3
15	**88,1**	**95,7**	**88,0**	**99,3**	**77,9**	**85,2**	**71,7**	**37,5**	**90,1**	**76,5**	**92,3**	**83,9**	**75,5**	**83,8**	**46,3**	**97,5**	**99,5**	**57,3**	**83,6**	**49,4**	**83,5**	**32,5**	**48,4**	**31,0**	**52,3**	**74,7**	**73,1**
16	76,8	100,0	83,9	95,2	94,3	46,6	55,4	36,5	93,5	72,2	79,9	76,8	67,5	70,2	28,6	96,1	91,6	56,4	80,6	46,8	46,9	36,0	66,7	32,9	78,8	40,6	67,3
17	71,2	99,1	85,3	96,8	88,1	64,7	62,8	38,7	97,7	82,1	59,5	86,2	67,3	58,1	31,0	100,0	96,3	57,1	81,5	52,3	62,0	48,4	59,6	34,4	73,1	72,2	70,2
18	70,1	99,1	81,9	100,0	95,0	66,0	58,9	38,2	88,6	80,7	66,1	82,6	66,4	59,2	29,4	95,4	90,7	45,6	80,4	51,1	70,0	42,9	73,2	29,6	69,3	34,2	67,9
19	72,1	97,5	82,5	100,0	75,1	55,8	59,9	45,7	87,0	77,3	60,7	83,2	76,0	58,8	32,0	98,0	97,5	62,6	80,3	53,7	77,2	33,0	78,4	36,3	75,1	37,1	69,0
20	39,4	100,0	87,0	94,0	78,5	64,3	61,4	35,2	85,1	80,7	74,9	74,6	67,4	51,6	37,3	60,7	96,4	64,2	82,8	32,9	73,8	33,4	72,6	23,9	47,9	33,7	63,6
21	62,5	94,4	85,2	100,0	44,1	62,3	58,2	29,7	68,8	77,0	69,7	89,8	78,3	53,5	30,8	95,1	96,7	57,1	77,4	60,9	65,9	51,3	84,6	19,9	70,7	34,3	66,1
22	65,0	95,0	80,8	95,5	77,8	59,2	85,5	29,1	71,6	83,8	63,7	81,4	69,7	52,4	33,9	96,8	100,0	50,2	83,2	54,3	68,1	38,9	78,0	38,1	74,1	36,5	67,8
23	66,4	91,0	79,0	99,4	76,8	58,2	52,6	36,2	100,0	77,3	66,1	79,2	69,6	45,4	38,9	90,2	96,3	56,0	83,8	56,9	61,3	50,1	76,6	18,3	75,0	39,4	66,9
24	72,4	98,0	77,4	86,7	81,1	59,1	48,5	25,3	74,0	77,2	66,9	83,2	76,2	53,2	69,9	95,4	96,9	61,1	85,9	59,6	68,9	48,1	73,8	29,2	73,0	34,6	68,3
25	74,4	98,9	80,3	86,6	79,9	97,0	49,2	48,9	76,4	70,3	83,9	90,7	99,5	56,8	32,2	77,7	94,0	51,4	85,1	53,2	85,9	42,7	74,7	22,4	70,5	34,5	69,9
26	**65,2**	**97,8**	**84,0**	**89,3**	**85,9**	**86,2**	**41,4**	**51,9**	**87,2**	**77,3**	**73,7**	**89,1**	**76,2**	**91,2**	**52,6**	**76,1**	**95,5**	**88,5**	**86,8**	**70,3**	**57,6**	**43,6**	**64,8**	**47,5**	**73,1**	**54,8**	**73,4**
27	83,6	97,5	88,4	86,0	89,2	59,7	39,0	27,9	78,0	85,0	59,3	97,0	89,5	64,9	47,0	91,3	100,0	56,1	91,4	59,3	61,4	41,4	69,4	29,4	74,6	32,8	69,2

28	67,2	90,8	75,5	88,8	87,3	59,0	33,7	43,7	87,1	59,1	65,2	89,1	71,4	53,3	35,7	86,1	100,0	52,7	81,8	52,8	59,1	36,5	68,8	8,5	78,0	62,4	65,1
29	78,4	94,5	81,6	89,4	68,8	53,0	41,2	21,8	80,0	66,5	95,7	87,9	84,3	58,5	45,5	79,3	100,0	59,6	86,2	51,9	64,5	58,5	89,3	4,5	70,1	28,5	66,9
30	78,5	90,1	85,2	82,5	69,7	81,6	78,9	30,6	65,5	61,2	91,3	98,3	76,1	73,1	76,9	84,6	93,0	57,3	75,7	43,1	56,8	34,1	61,9	21,4	84,5	29,5	68,5
31	81,2	93,7	100,0	84,5	74,7	56,4	35,7	28,9	74,6	78,1	66,4	92,1	80,7	56,9	70,8	78,3	100,0	66,6	77,6	41,3	70,3	33,3	67,4	7,4	71,9	57,1	67,1
32	84,9	85,3	100,0	90,7	81,8	56,1	35,2	30,5	62,7	78,0	58,8	95,0	84,6	42,9	52,2	80,4	92,6	55,3	73,8	36,6	57,6	71,4	65,7	5,7	71,9	28,4	64,5
33	72,5	91,5	100,0	87,8	82,9	59,8	40,0	33,5	70,9	81,2	65,4	86,6	90,6	87,0	47,6	93,5	97,2	60,2	99,4	41,4	67,4	54,8	63,9	16,2	75,7	25,2	68,9
34	65,3	91,4	95,4	89,4	87,0	56,7	37,1	31,1	63,6	83,9	59,6	93,8	86,1	62,7	60,6	83,1	91,1	60,3	65,5	42,7	45,3	41,6	71,3	14,7	69,5	27,0	64,4
35	71,2	94,1	93,8	87,8	72,9	61,0	65,8	72,0	67,8	82,3	65,0	80,6	76,0	58,7	50,9	82,5	97,6	68,0	73,5	56,3	63,5	41,3	81,1	13,1	76,6	26,2	68,4
36	73,0	94,2	93,0	87,6	69,7	63,6	33,8	45,7	70,7	84,4	69,4	91,0	87,5	65,9	91,2	75,7	92,7	63,5	67,1	59,1	63,1	38,1	70,3	39,2	69,1	27,1	68,7
37	76,0	87,5	94,8	90,4	91,1	76,5	32,3	20,2	89,6	86,6	90,9	84,9	81,1	58,5	55,6	93,7	99,5	85,2	67,0	49,6	64,7	38,0	74,6	24,7	66,1	56,2	70,6
38	71,1	88,6	96,2	96,8	74,6	59,2	69,8	86,9	67,1	89,8	80,6	82,3	89,0	67,3	55,0	80,0	95,6	82,5	74,7	85,2	56,6	41,3	76,8	31,2	68,6	26,5	72,8
39	68,9	86,0	92,8	91,9	83,6	67,5	39,9	58,8	69,4	82,4	67,1	91,1	87,5	75,4	79,3	75,4	92,6	84,3	66,5	49,2	93,9	32,7	80,6	15,0	62,8	51,9	71,0
40	78,1	89,5	95,1	96,6	87,1	91,0	71,8	19,8	72,4	97,2	62,9	91,9	79,9	66,0	57,2	80,7	94,6	55,1	74,6	57,4	69,6	81,4	87,9	35,0	66,9	22,8	72,4
41	76,9	85,9	94,4	93,0	79,2	70,0	41,0	27,1	99,8	48,9	60,5	91,9	88,8	64,0	56,4	83,8	91,7	66,3	95,3	70,0	73,4	42,6	77,4	84,9	67,7	25,4	71,4
42	70,0	84,3	90,7	95,4	80,7	69,2	48,7	62,9	63,3	75,2	65,0	86,5	79,7	67,8	43,2	82,5	87,6	74,9	65,6	52,8	74,2	32,6	68,8	18,7	76,2	39,9	67,6
43	94,5	84,7	89,2	87,7	77,8	70,3	47,3	28,0	66,8	72,3	72,3	76,5	87,5	66,6	45,4	81,1	94,0	65,8	68,2	53,0	65,9	37,6	90,3	26,8	94,7	25,7	68,1
44	78,8	85,6	90,1	88,6	70,0	66,0	44,1	20,2	67,3	73,2	60,4	79,0	90,9	73,0	44,4	98,3	93,5	66,5	87,5	53,7	90,1	38,0	82,4	20,7	81,4	61,2	69,4
45	98,1	94,0	86,6	89,1	78,8	62,7	30,0	27,8	66,7	73,0	57,8	90,9	82,7	96,5	84,9	89,0	86,9	85,3	69,9	52,7	68,1	44,9	79,8	32,9	64,3	64,2	71,4
46	79,3	95,0	92,4	89,1	81,1	85,6	76,4	42,7	58,6	85,1	60,6	80,9	97,7	69,4	45,0	85,5	90,0	92,2	65,5	47,3	64,7	67,1	74,9	16,3	69,7	48,8	71,6
47	80,1	94,6	95,8	84,6	91,3	66,5	47,9	25,3	97,2	79,4	51,9	78,1	81,4	63,6	37,1	94,1	92,0	75,4	59,1	49,6	78,7	42,3	96,7	42,6	68,5	23,4	69,1
48	80,3	87,9	89,8	96,4	92,2	96,3	47,7	25,1	71,0	84,6	54,2	86,6	87,3	71,3	32,5	92,0	93,6	69,1	74,6	51,8	76,4	55,0	70,9	27,4	67,0	30,0	69,7
49	77,8	92,1	94,5	94,5	65,5	58,0	46,8	28,3	64,0	79,7	55,4	81,6	83,4	57,6	46,1	91,0	95,5	67,5	90,4	38,7	74,1	44,3	75,8	29,4	70,2	49,7	67,4
50	73,2	86,6	89,9	88,4	76,5	63,8	55,3	28,5	56,1	85,6	59,2	80,2	82,5	73,9	44,4	78,8	99,5	96,8	54,4	62,5	92,1	47,1	74,9	57,8	73,4	29,7	69,7
Avg.	76,4	90,8	87,9	93,1	77,4	65,9	54,8	38,5	76,8	76,1	67,4	80,6	78,7	62,6	45,6	85,1	90,5	61,3	79,3	50,3	67,7	48,5	72,0	30,0	69,1	44,1	

Table A.9 Average of accuracies, according to the filter, obtained for all users

Filter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
None	**83,7**	**98,5**	**90,9**	**100,0**	**84,0**	**79,8**	**51,9**	**31,1**	**81,4**	**70,8**	**78,1**	**92,7**	**80,8**	**86,5**	**57,2**	**98,7**	**94,7**	**61,0**	**78,4**	**59,4**	**69,3**	**44,8**	**82,5**	**20,4**	**66,1**	**42,3**	**72,5**
And	**84,4**	**96,2**	**90,5**	**95,2**	**86,4**	**69,0**	**54,3**	**31,4**	**86,5**	**86,0**	**67,0**	**85,4**	**93,3**	**62,5**	**49,6**	**86,7**	**93,8**	**66,9**	**75,5**	**54,2**	**63,7**	**51,9**	**84,4**	**19,4**	**76,4**	**32,8**	**70,9**
Or	61,7	75,0	80,0	92,4	67,6	45,3	48,2	28,4	64,0	64,4	39,4	68,0	24,3	26,8	27,9	67,8	74,5	39,8	74,1	38,9	39,1	42,7	42,7	27,4	47,6	39,0	51,8
Kinect	46,3	88,0	82,8	86,4	52,8	25,2	31,2	23,8	51,7	80,8	48,3	71,6	94,2	41,3	28,5	82,5	94,9	60,3	72,4	62,5	65,2	36,1	77,4	32,3	93,8	21,7	59,7
Library	**84,0**	**96,8**	**87,7**	**96,7**	**87,8**	**81,1**	**63,5**	**37,8**	**83,7**	**76,2**	**68,2**	**80,9**	**88,6**	**67,4**	**38,5**	**90,0**	**84,5**	**50,6**	**79,7**	**30,0**	**71,6**	**38,7**	**69,1**	**23,0**	**58,1**	**41,7**	**68,3**
Avg.	72,0	90,9	86,4	94,2	75,7	60,1	49,8	30,5	73,5	75,6	60,2	79,7	76,2	56,9	40,3	85,2	88,5	55,7	76,0	49,0	61,8	42,8	71,2	24,5	68,4	35,5	

Table A.10 Average of accuracies, according to the hand variation, obtained for all users

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
1	93,4	94,8	85,7	93,3	61,7	54,9	69,2	35,2	50,5	82,3	73,3	8,5	71,7	28,5	48,1	60,7	80,6	26,9	64,0	32,9	57,8	50,7	48,8	18,7	35,2	49,1	56,8
2	84,7	90,1	89,1	85,1	63,8	51,8	71,3	46,9	51,4	65,5	54,4	38,4	65,4	66,8	31,0	51,0	76,5	32,7	88,0	32,0	52,4	50,9	60,5	37,0	51,5	40,5	58,8
3	97,7	96,9	93,5	97,0	71,4	52,7	61,3	47,0	56,5	54,1	50,0	41,1	73,3	46,0	25,3	53,6	78,8	35,8	78,2	33,1	51,7	61,9	57,8	44,0	62,5	44,9	60,2
4	83,9	98,0	96,0	85,5	62,8	57,6	64,0	48,3	72,7	66,9	61,2	60,8	71,0	40,1	26,5	46,1	73,9	44,2	85,3	28,3	67,0	62,7	66,1	37,4	57,4	49,2	62,0
5	89,2	82,0	93,9	100,0	60,0	60,0	59,4	45,4	78,8	64,6	47,0	68,7	66,2	44,9	18,1	83,4	68,5	45,1	79,7	29,3	61,5	63,1	65,8	36,7	53,9	61,9	62,6
6	78,6	68,3	76,1	97,3	68,2	59,4	63,6	46,3	75,3	51,2	55,1	74,0	66,2	45,5	27,6	78,0	79,1	41,4	82,6	36,2	77,4	73,2	69,7	49,5	68,2	48,9	63,7
7	64,6	70,3	84,3	98,8	73,7	76,7	58,6	24,4	80,0	62,9	67,7	75,3	66,9	41,6	35,7	92,6	79,3	42,7	82,2	40,2	49,7	65,8	76,8	47,7	54,4	57,8	64,2
8	74,6	81,1	87,4	99,6	67,8	56,2	53,8	42,3	80,1	70,6	53,5	76,9	87,9	52,6	37,8	87,9	84,2	43,3	84,6	45,1	58,1	43,0	70,1	37,7	74,9	63,7	66,0
9	49,3	91,7	86,3	100,0	80,7	61,4	52,6	33,1	69,5	82,5	42,6	85,2	80,8	56,7	43,0	96,2	84,5	48,1	85,6	68,7	59,1	67,8	61,8	39,8	72,9	54,9	67,5
10	**71,5**	**92,3**	**85,4**	**98,6**	**80,6**	**74,8**	**59,4**	**29,3**	**72,1**	**80,2**	**48,7**	**88,9**	**72,5**	**59,1**	**48,7**	**92,8**	**86,4**	**62,1**	**90,1**	**54,6**	**87,9**	**53,4**	**54,2**	**41,0**	**79,1**	**47,4**	**69,7**
11	77,1	89,4	85,9	99,0	70,4	66,4	56,1	48,2	86,7	75,5	43,2	83,9	80,4	58,1	44,7	94,4	73,4	41,7	87,6	48,7	67,5	66,9	58,0	37,7	72,3	60,6	68,2
12	76,9	92,2	83,5	99,8	89,0	51,3	54,2	45,3	85,5	79,2	60,1	61,3	72,9	72,6	29,2	96,4	78,9	73,2	87,2	61,5	72,8	44,8	68,7	40,4	69,0	35,9	68,5
13	77,9	86,0	78,5	99,6	82,0	57,0	71,7	30,0	79,0	69,5	68,9	72,9	72,9	54,4	38,1	98,6	75,8	64,1	88,9	37,3	72,6	44,7	87,0	32,4	80,6	51,5	68,1
14	85,4	92,4	75,1	99,2	87,8	50,7	68,6	20,0	86,3	83,1	79,4	80,7	75,6	71,6	36,2	97,8	78,2	45,7	85,4	39,9	63,6	42,5	58,3	38,2	62,3	53,2	67,6
15	71,1	94,4	86,7	99,5	80,6	54,9	75,3	39,3	92,9	71,8	80,6	85,1	73,0	74,0	38,1	97,3	71,0	59,3	85,2	46,2	63,2	42,8	46,1	27,1	62,3	62,1	68,5
16	**78,3**	**96,8**	**87,0**	**98,3**	**91,8**	**55,1**	**54,0**	**34,2**	**91,4**	**75,1**	**64,9**	**80,7**	**75,2**	**73,8**	**38,9**	**96,0**	**92,6**	**66,5**	**75,8**	**53,7**	**56,8**	**41,2**	**67,2**	**46,5**	**75,8**	**46,3**	**69,8**
17	73,7	97,9	86,3	99,0	87,6	61,7	64,9	38,1	94,3	81,2	58,2	83,9	71,7	58,8	28,6	97,1	93,8	53,7	79,7	50,8	60,9	56,6	62,4	36,7	70,6	45,9	69,0
18	74,2	98,9	87,7	99,2	95,8	63,9	61,3	39,9	89,4	80,5	69,2	86,8	68,4	60,4	29,6	97,4	93,8	49,3	79,7	54,9	66,5	43,9	76,7	32,7	72,2	35,3	69,5
19	**76,5**	**98,5**	**86,5**	**98,9**	**77,3**	**57,9**	**60,2**	**46,7**	**88,7**	**77,7**	**60,9**	**84,3**	**73,0**	**60,4**	**31,5**	**98,6**	**99,0**	**53,1**	**79,9**	**63,4**	**76,5**	**34,9**	**78,7**	**44,5**	**77,1**	**41,5**	**70,2**
20	61,7	86,9	83,6	98,0	80,1	53,2	60,4	38,2	79,1	82,1	73,5	75,2	70,4	48,8	33,3	84,6	99,1	54,7	83,2	47,7	74,9	38,3	73,5	28,6	59,8	28,6	65,3
21	60,5	88,9	85,0	99,6	64,5	49,8	55,1	29,1	67,3	73,8	72,5	88,2	73,8	49,3	28,6	96,2	98,5	61,5	80,0	58,6	67,1	48,9	84,8	23,2	71,7	35,0	65,8
22	64,1	92,6	83,2	93,3	73,6	58,9	62,2	28,0	73,6	81,2	66,7	79,9	71,8	48,9	35,6	98,6	97,9	53,5	79,6	56,2	65,8	52,0	75,9	22,8	69,3	34,9	66,2
23	68,9	94,1	81,7	97,5	80,5	60,0	54,1	36,0	79,9	80,4	63,9	80,2	71,4	47,4	38,7	92,5	98,5	53,3	85,5	55,3	63,8	48,4	75,0	21,3	75,4	37,0	66,9
24	71,4	93,3	80,8	85,7	79,6	58,6	50,6	29,5	73,2	73,4	67,0	84,0	72,8	59,1	45,8	92,8	96,2	57,5	86,2	57,9	71,3	45,2	77,7	27,5	78,7	34,2	67,3
25	72,5	92,8	82,9	89,1	83,5	81,7	46,8	34,8	83,1	71,1	75,5	88,7	79,0	50,3	36,2	80,5	96,4	55,6	85,4	58,6	72,5	39,8	76,9	21,5	73,5	38,1	68,0
26	68,5	95,3	81,0	88,8	88,3	77,4	38,2	51,2	85,0	74,6	68,4	89,8	73,8	66,8	39,7	79,6	96,8	60,5	85,0	65,6	62,5	45,0	68,9	31,5	74,2	39,1	69,1
27	**81,5**	**94,0**	**81,6**	**87,2**	**87,8**	**60,4**	**47,1**	**39,4**	**80,8**	**80,3**	**72,5**	**95,2**	**80,7**	**61,9**	**57,3**	**93,0**	**98,7**	**53,9**	**91,1**	**63,6**	**67,6**	**37,7**	**76,9**	**22,2**	**72,2**	**47,2**	**70,4**

28	69,4	91,3	75,5	87,4	88,4	63,4	45,2	28,1	83,4	60,1	72,5	88,5	76,9	53,5	37,5	88,4	99,8	49,7	83,1	56,7	67,4	39,7	67,1	18,2	73,9	37,3	65,5
29	81,7	90,6	85,2	87,5	71,7	54,8	37,8	26,5	77,2	65,3	74,2	85,3	77,3	58,3	51,2	82,1	96,6	56,3	85,9	55,3	69,6	47,0	71,1	9,7	71,2	43,2	65,9
30	77,0	88,5	82,7	89,4	77,4	68,8	64,9	31,6	72,5	62,8	71,8	95,5	79,2	52,7	51,6	84,8	96,7	57,6	78,8	46,5	58,5	36,0	62,1	20,5	78,3	29,5	66,0
31	82,3	90,9	96,9	87,0	75,8	57,4	40,4	33,5	75,0	76,5	64,1	92,1	79,9	50,9	62,3	78,8	97,9	57,4	75,5	38,7	68,6	38,0	72,1	11,1	70,5	37,6	65,8
32	82,6	88,9	100,0	89,9	84,7	57,6	37,5	32,6	67,4	79,9	57,4	91,9	86,0	44,4	48,6	80,4	95,4	56,9	71,0	38,6	59,1	52,3	64,5	11,0	75,4	44,9	65,3
33	71,6	91,8	98,9	89,6	86,0	60,9	43,8	32,5	70,1	75,0	59,4	89,1	87,5	71,5	48,7	83,1	93,2	59,7	82,0	47,6	50,0	52,8	69,3	15,9	75,0	22,8	66,5
34	76,6	92,4	97,9	87,7	85,1	62,5	39,6	33,9	64,9	81,8	62,7	93,3	84,5	66,7	58,7	80,9	92,4	67,3	68,0	44,7	50,7	44,7	74,4	16,3	71,7	24,5	66,3
35	71,7	95,8	92,0	91,2	76,5	59,1	44,6	46,4	65,9	82,1	61,0	86,1	79,2	60,3	56,9	79,7	96,0	67,6	71,5	65,8	63,2	41,2	77,6	13,9	81,1	24,1	67,3
36	73,6	93,4	97,0	89,3	72,7	71,6	35,8	35,8	67,0	81,4	74,6	88,1	84,7	63,8	64,4	78,3	93,9	61,6	68,0	58,6	61,4	44,7	69,1	35,4	69,4	23,6	67,6
37	75,0	89,5	97,1	87,4	77,2	73,8	40,9	30,7	80,3	82,8	75,9	88,1	83,6	58,9	56,1	82,3	94,6	69,5	70,0	52,7	61,5	38,1	77,7	30,3	67,2	42,0	68,6
38	75,7	91,1	95,9	96,1	69,6	64,6	40,5	39,8	67,4	87,1	71,8	84,3	88,0	67,1	54,5	81,1	92,4	70,5	69,6	63,2	58,5	37,1	75,1	30,8	71,3	28,2	68,1
39	**72,3**	**89,4**	**95,6**	**94,9**	**83,1**	**63,9**	**41,2**	**49,9**	**73,4**	**83,2**	**65,2**	**89,5**	**83,2**	**73,8**	**66,1**	**79,2**	**93,5**	**77,6**	**69,6**	**54,4**	**69,7**	**32,2**	**79,0**	**28,2**	**67,1**	**40,4**	**69,8**
40	74,5	90,0	95,3	93,5	87,4	75,8	44,0	24,6	65,5	86,1	71,9	91,5	82,1	69,9	54,5	79,9	91,7	73,5	70,4	53,6	80,6	44,1	82,3	24,3	65,9	26,3	69,2
41	73,3	90,3	91,6	92,7	77,4	70,4	36,2	23,8	77,1	75,8	68,0	92,9	85,6	63,4	66,9	82,3	90,7	69,5	74,2	66,2	76,9	35,6	79,9	37,9	66,6	25,8	68,9
42	71,6	85,7	91,6	95,4	75,4	73,7	53,1	36,4	69,0	81,4	67,0	89,0	90,1	64,2	44,4	84,4	90,6	71,3	64,1	56,5	77,1	34,4	72,1	23,9	78,6	32,1	68,2
43	85,4	88,5	89,6	88,3	78,4	75,7	44,6	27,8	69,2	76,2	77,1	79,9	86,5	70,0	43,8	84,9	90,6	70,1	69,2	51,7	69,3	35,6	79,0	30,2	81,2	24,2	68,0
44	77,4	89,4	86,0	90,7	68,5	68,7	51,0	17,4	72,4	77,3	65,7	82,4	88,1	64,2	43,5	86,8	90,9	73,9	72,4	68,1	75,6	36,5	82,3	25,7	70,9	38,1	67,8
45	82,5	91,5	88,6	91,3	77,8	59,9	40,6	22,9	69,4	73,2	55,8	89,0	85,1	71,1	51,8	86,0	91,5	70,6	69,2	53,9	80,2	41,6	77,7	29,4	72,1	42,6	67,9
46	78,1	91,3	90,6	86,0	77,3	69,0	49,7	33,0	59,3	86,9	57,6	81,4	87,9	73,1	49,7	85,7	90,2	82,8	60,4	58,3	68,9	50,2	78,9	18,1	72,3	27,7	67,9
47	77,1	91,1	95,7	83,4	77,7	65,9	47,2	30,3	71,0	77,4	74,8	81,7	84,8	59,2	38,1	90,6	90,5	73,1	64,6	46,4	77,4	52,2	80,7	36,6	72,6	27,2	68,0
48	80,4	88,5	92,9	88,2	80,5	70,4	46,8	29,1	62,8	81,2	61,6	83,0	86,3	76,5	36,4	93,1	93,3	71,8	64,6	49,4	74,5	47,5	72,9	26,9	78,7	26,4	67,8
49	78,8	91,2	91,9	85,8	70,9	60,4	46,1	35,6	70,7	78,2	62,8	83,3	83,7	67,4	43,2	87,5	94,5	73,3	71,6	42,8	77,6	43,2	80,2	28,4	74,7	37,7	67,7
50	76,4	90,4	92,2	89,5	68,4	73,2	50,8	38,0	66,4	85,5	59,3	82,3	84,5	64,7	42,6	79,9	98,8	77,1	56,0	48,9	86,6	39,4	74,4	31,2	79,5	25,7	67,8
Avg.	75,9	90,6	88,3	93,0	77,6	62,9	52,3	35,3	74,4	75,8	64,6	80,5	78,3	59,3	42,9	85,1	89,7	58,8	77,5	50,8	67,0	46,6	71,3	29,6	70,2	39,5	

Appendix B – Results of the SLR Module during Dynamic Validation

Table B.1 Average of accuracies, obtained for user 1

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	78,1	63,6	73,6	65,4	58,4	68,6	52,1	59,7	67,6	74,1	57,0	70,2	72,3	72,3	33,8	72,2	71,6	51,7	70,2	68,3	71,6	38,6	76,6	45,6	43,8	44,9	62,4
	16	78,6	64,1	61,7	65,8	58,9	67,7	57,6	55,5	76,9	72,2	59,3	64,1	61,4	77,9	30,8	80,7	65,6	47,1	58,4	53,5	53,7	50,7	56,2	44,9	44,0	35,7	59,3
	10	66,3	62,3	54,3	68,0	66,6	64,9	49,9	47,4	61,1	73,7	55,7	63,3	58,6	75,0	26,3	78,2	60,7	43,4	70,1	61,3	62,7	39,4	52,3	41,1	46,0	29,7	56,9
	19	**76,1**	**63,3**	**62,4**	**66,0**	**58,2**	**70,0**	**55,4**	**56,5**	**76,1**	**76,4**	**63,0**	**67,0**	**63,2**	**76,0**	**33,9**	**81,7**	**71,7**	**58,7**	**71,1**	**70,6**	**68,6**	**47,9**	**69,6**	**48,5**	**50,9**	**41,7**	**63,2**
	27	77,1	76,2	67,6	66,8	61,1	69,5	50,4	56,6	71,1	74,1	57,3	67,0	67,1	75,5	32,1	75,5	70,0	50,9	69,0	67,3	71,0	37,9	69,4	43,3	46,0	39,5	61,9
Filters	**None**	**75,3**	**65,5**	**62,9**	**72,2**	**63,5**	**71,9**	**48,4**	**58,5**	**71,8**	**71,0**	**67,7**	**65,6**	**50,5**	**81,6**	**37,6**	**93,5**	**76,3**	**54,9**	**72,2**	**72,5**	**66,9**	**50,9**	**68,9**	**49,3**	**48,3**	**49,9**	**64,1**
	And	73,4	66,8	64,7	62,1	56,5	64,6	55,5	53,2	70,2	83,7	55,8	71,4	72,9	70,6	29,1	70,0	68,5	54,6	66,1	66,6	66,8	40,0	66,1	42,7	57,1	32,7	60,8
	Library	77,0	65,3	64,1	64,8	61,9	67,9	55,4	53,7	69,6	67,6	51,8	61,9	70,1	73,8	27,4	69,6	58,9	41,5	65,0	53,5	62,9	37,9	59,6	42,0	33,0	32,3	57,3
Average		75,2	65,9	63,9	66,4	60,6	68,1	53,1	55,1	70,6	74,1	58,4	66,3	64,5	75,3	31,4	77,7	67,9	50,3	67,8	64,2	65,5	42,9	64,9	44,7	46,1	38,3	

Table B.2 Average of approximations, obtained for user 1

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	85,1	85,3	83,8	85,8	83,6	84,0	88,5	83,7	87,2	86,2	84,9	83,5	79,9	78,9	83,2	82,0	86,4	86,5	89,6	85,5	86,5	84,8	84,9	83,6	84,3	85,1	84,7
	16	78,1	79,4	74,0	78,6	74,1	73,2	78,4	73,9	79,5	75,4	77,1	69,6	69,8	72,2	73,6	75,6	74,2	74,4	77,5	75,6	77,1	73,4	74,8	70,2	72,7	74,0	74,9
	10	67,1	70,5	63,9	70,4	62,6	63,7	67,0	63,3	67,5	64,1	65,8	57,9	60,2	63,4	62,2	66,7	62,6	63,6	68,0	66,4	68,3	63,2	65,4	58,6	61,9	63,4	64,5
	19	**80,3**	**81,2**	**76,8**	**82,0**	**77,5**	**77,5**	**81,4**	**76,7**	**81,6**	**79,1**	**80,2**	**74,6**	**73,3**	**74,0**	**76,5**	**78,1**	**78,6**	**78,8**	**83,1**	**80,1**	**81,2**	**77,2**	**79,5**	**74,4**	**77,2**	**78,4**	**78,4**
	27	84,1	83,5	80,5	84,3	81,2	80,4	85,7	81,2	84,2	82,9	82,8	79,2	77,1	77,3	81,4	81,1	83,1	83,0	87,1	83,1	84,2	81,3	82,2	79,2	80,5	82,2	82,0
Filters	**None**	**94,7**	**93,6**	**93,0**	**95,3**	**94,0**	**93,0**	**94,4**	**92,6**	**94,5**	**92,7**	**93,6**	**92,5**	**91,0**	**94,0**	**92,2**	**94,7**	**92,5**	**92,4**	**94,7**	**92,8**	**94,5**	**92,8**	**93,6**	**93,3**	**91,7**	**93,3**	**93,4**
	And	68,4	68,2	63,1	68,9	63,1	63,6	70,2	62,9	69,5	65,1	66,3	58,9	58,6	60,0	63,3	62,7	64,0	65,6	71,2	66,4	68,4	62,8	65,7	60,2	60,8	64,6	64,7
	Library	73,7	78,1	71,4	76,5	70,4	70,7	76,1	71,8	76,0	74,9	74,6	67,5	66,4	65,4	70,7	72,6	74,4	73,7	77,3	75,2	75,5	72,3	72,7	66,1	73,5	71,9	72,7
Average		78,9	80,0	75,8	80,2	75,8	75,8	80,2	75,8	80,0	77,5	78,2	73,0	72,0	73,2	75,4	76,7	77,0	77,3	81,0	78,1	79,5	76,0	77,4	73,2	75,3	76,6	

Table B.3 Average of approximation differences, obtained for user 1

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	1,6	2,5	4,1	4,2	5,3	3,2	2,2	3,8	3,2	2,9	4,0	4,3	3,5	3,4	6,5	1,5	5,4	3,7	2,5	2,5	3,6	4,0	1,9	3,0	6,5	4,9	3,6
	16	1,6	1,7	4,6	4,8	4,3	3,6	2,0	4,0	3,3	3,3	3,7	4,1	3,1	2,9	5,5	1,1	4,9	4,3	2,5	2,1	3,9	3,6	1,8	2,6	4,8	4,4	3,4
	10	2,0	2,1	4,1	3,5	3,1	2,9	2,4	4,1	3,3	2,8	3,7	3,7	2,5	2,3	4,9	1,5	4,0	3,8	2,0	1,6	3,0	3,1	1,8	2,2	3,9	3,9	3,0
	19	**1,6**	**1,9**	**4,4**	**4,6**	**4,7**	**3,5**	**2,2**	**3,6**	**3,3**	**3,1**	**4,1**	**4,1**	**3,0**	**3,1**	**5,9**	**1,1**	**4,9**	**4,1**	**2,3**	**1,7**	**3,4**	**4,0**	**1,3**	**2,7**	**4,9**	**4,6**	**3,4**
	27	1,6	2,8	4,4	4,4	4,3	3,3	1,9	4,6	3,9	2,9	3,7	4,4	3,3	2,9	5,9	1,2	5,8	4,5	2,2	2,0	3,3	4,3	1,7	2,6	6,1	4,8	3,6
Filters	**None**	**0,5**	**0,9**	**1,6**	**2,3**	**1,1**	**1,2**	**0,7**	**1,6**	**1,1**	**0,9**	**1,5**	**1,3**	**1,5**	**0,5**	**2,0**	**0,2**	**1,9**	**1,5**	**0,7**	**0,6**	**0,7**	**1,2**	**0,5**	**0,8**	**1,3**	**1,4**	**1,1**
	And	2,0	1,9	3,8	3,4	4,5	3,9	2,6	4,6	4,2	2,5	3,8	3,7	2,6	3,3	6,3	1,5	3,7	3,8	2,9	2,1	3,5	3,3	1,9	2,9	5,1	5,1	3,4
	Library	2,6	3,8	7,6	7,2	7,4	4,8	3,0	5,9	4,9	5,7	6,3	7,5	5,1	5,0	8,9	2,1	9,4	6,9	3,3	3,3	6,1	6,9	2,8	4,2	9,3	7,1	5,7
Average		1,7	2,2	4,3	4,3	4,3	3,3	2,1	4,0	3,4	3,0	3,9	4,1	3,1	2,9	5,7	1,3	5,0	4,1	2,3	2,0	3,4	3,8	1,7	2,6	5,2	4,5	

Table B.4 Average of accuracies, obtained for user 2

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	79,6	63,6	73,6	58,3	62,6	72,4	56,8	59,0	67,1	54,7	60,7	69,7	72,0	69,9	32,6	69,3	67,4	54,8	71,0	71,5	70,1	27,6	81,0	43,7	43,8	49,9	61,6
	16	76,4	59,3	60,3	66,4	59,3	63,4	60,8	55,0	75,3	69,4	60,1	63,1	63,3	82,4	34,2	85,3	68,5	43,6	55,5	49,3	54,5	50,7	56,2	48,1	39,4	39,1	59,2
	10	64,9	60,7	55,4	72,8	70,6	66,2	45,5	49,7	57,1	73,9	54,7	69,6	60,7	75,0	28,5	79,3	60,7	40,5	69,2	58,6	58,4	35,3	55,4	46,0	43,0	30,8	57,0
	19	76,1	61,9	64,1	70,0	60,9	55,4	51,5	55,2	80,6	78,3	58,5	63,2	63,5	74,1	38,1	78,4	74,4	56,1	70,9	72,9	73,7	27,8	68,8	47,8	47,2	39,9	61,9
	27	**81,2**	**78,6**	**68,6**	**61,8**	**56,9**	**71,9**	**58,8**	**55,2**	**71,6**	**78,5**	**65,2**	**65,8**	**66,1**	**75,7**	**30,6**	**77,9**	**78,2**	**50,1**	**73,1**	**71,3**	**71,9**	**41,2**	**67,6**	**59,0**	**46,2**	**34,7**	**63,8**
Filters	**None**	**77,2**	**64,4**	**66,7**	**74,5**	**61,8**	**72,1**	**48,8**	**60,1**	**69,6**	**68,0**	**63,2**	**60,9**	**53,3**	**78,4**	**41,5**	**92,7**	**76,2**	**58,8**	**68,0**	**71,1**	**63,2**	**48,0**	**73,8**	**50,6**	**53,1**	**53,0**	**64,2**
	And	70,6	75,9	68,4	62,8	63,2	64,1	57,6	48,8	74,4	84,8	57,8	73,4	74,0	75,4	27,5	76,0	69,2	54,3	71,0	75,3	69,6	39,1	64,0	39,9	61,4	27,8	62,6
	Library	80,8	69,1	68,3	62,7	65,2	66,8	53,6	54,6	65,9	71,2	50,9	59,4	68,0	76,8	26,1	68,4	72,9	49,3	68,0	54,6	73,1	34,5	79,4	44,7	29,3	30,9	59,4
Average		75,9	66,7	65,7	66,2	62,6	66,5	54,2	54,7	70,2	72,4	58,9	65,6	65,1	76,0	32,4	78,4	70,9	50,9	68,3	65,6	66,8	38,0	68,3	47,5	45,4	38,3	

Table B.5 Average of approximations, obtained for user 2

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	0
Variation	39	92,7	82,4	77,1	92,6	83,8	77,5	85,3	77,9	87,2	80,1	81,5	74,1	77,3	78,7	82,4	90,5	79,6	80,7	99,6	94,1	93,5	82,4	78,3	78,9	89,5	90,5	84,2
	16	80,1	83,8	80,7	78,7	77,2	63,7	84,9	64,5	75,8	69,6	69,8	64,2	61,9	78,0	79,9	78,8	75,5	74,6	80,6	70,0	75,7	82,7	66,8	68,3	76,6	64,7	74,1
	10	74,1	68,1	73,4	72,4	69,0	65,7	66,3	65,7	59,6	67,4	69,3	67,4	63,8	73,1	53,1	74,2	68,8	73,0	67,2	73,8	68,0	59,7	61,2	53,6	68,1	65,8	67,0
	19	81,2	73,3	84,8	75,3	72,6	69,7	80,6	72,4	78,3	75,8	84,3	74,0	81,5	71,9	73,4	81,1	79,8	75,8	83,6	88,5	90,4	80,5	85,6	82,1	76,4	79,2	78,9
	27	**87,5**	**75,9**	**88,7**	**80,2**	**77,6**	**73,3**	**91,6**	**90,1**	**79,0**	**78,6**	**84,5**	**87,2**	**75,5**	**67,9**	**72,7**	**79,7**	**78,1**	**92,6**	**80,0**	**73,3**	**83,1**	**77,9**	**79,4**	**71,3**	**72,6**	**81,7**	**80,0**
Filters	**None**	**99,5**	**87,8**	**92,4**	**96,6**	**88,4**	**90,0**	**100,0**	**96,5**	**100,0**	**90,2**	**84,4**	**98,1**	**83,3**	**86,1**	**87,8**	**90,2**	**87,9**	**85,9**	**97,9**	**87,0**	**86,8**	**99,5**	**100,0**	**100,0**	**90,6**	**83,7**	**92,0**
	And	60,6	61,7	54,2	70,5	66,3	54,8	68,7	59,5	64,1	59,8	74,7	56,8	52,4	56,1	53,5	60,0	56,5	73,5	66,8	75,9	68,9	69,1	72,8	68,1	69,0	73,0	64,1
	Library	82,1	71,0	76,5	85,4	69,9	71,5	73,1	73,6	72,2	72,3	83,3	69,2	67,5	70,5	66,0	74,8	65,3	79,3	77,8	69,6	66,9	74,3	75,6	67,3	65,2	80,2	73,1
Average		82,2	75,5	78,5	81,5	75,6	70,8	81,3	75,0	77,0	74,2	79,0	73,9	70,4	72,8	71,1	78,7	73,9	79,4	81,7	79,0	79,2	78,3	77,5	73,7	76,0	77,4	

Table B.6 Average of approximation differences, obtained for user 2

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	0
Variation	39	1,7	1,0	4,9	2,6	3,6	1,7	1,2	3,6	3,4	4,9	4,1	5,0	4,9	4,1	5,7	0,4	5,7	4,1	4,5	2,8	2,1	3,9	3,1	1,8	8,4	3,1	3,5
	16	0,6	0,2	3,6	5,8	6,2	5,4	2,1	4,1	5,2	2,8	3,8	2,7	3,3	3,8	6,0	2,3	5,0	3,4	3,2	1,6	2,9	2,3	0,0	3,5	4,0	3,8	3,4
	10	1,1	4,0	2,8	4,1	2,9	4,2	2,8	5,5	4,2	1,5	5,3	4,9	3,9	0,5	3,0	1,1	5,9	2,5	1,1	2,8	2,5	4,9	3,3	3,6	3,5	3,7	3,3
	19	2,2	3,8	3,3	4,7	4,7	3,6	1,1	2,8	4,5	5,1	5,5	4,4	3,9	1,8	7,1	2,1	5,2	3,1	2,9	3,3	3,2	4,7	0,9	2,5	3,9	4,0	3,6
	27	**1,1**	**2,9**	**4,3**	**4,4**	**4,5**	**3,5**	**1,2**	**5,6**	**2,1**	**4,0**	**3,2**	**4,0**	**1,5**	**3,9**	**4,3**	**1,0**	**6,0**	**3,5**	**1,0**	**2,7**	**2,5**	**5,9**	**0,0**	**3,3**	**5,2**	**2,9**	**3,3**
Filters	**None**	**2,4**	**1,8**	**0,0**	**1,6**	**1,5**	**2,1**	**0,6**	**1,7**	**0,0**	**2,6**	**1,7**	**1,1**	**1,9**	**1,3**	**3,1**	**0,1**	**1,3**	**3,3**	**0,4**	**1,8**	**2,4**	**3,0**	**0,0**	**0,0**	**0,4**	**1,7**	**1,5**
	And	2,9	0,3	2,9	3,2	3,9	3,0	3,9	3,9	4,3	4,2	5,4	3,7	1,0	2,8	4,6	0,4	4,7	4,4	3,2	4,0	3,3	4,1	2,3	2,8	5,6	6,7	3,5
	Library	2,7	4,1	7,2	8,9	7,9	3,4	3,0	6,4	6,8	5,1	5,5	5,7	3,9	6,8	8,4	2,3	7,5	8,7	1,3	3,3	6,3	5,8	2,6	3,7	7,6	7,4	5,5
Average		1,8	2,3	3,6	4,4	4,4	3,4	2,0	4,2	3,8	3,8	4,3	3,9	3,1	3,1	5,3	1,2	5,2	4,1	2,2	2,8	3,2	4,3	1,5	2,6	4,8	4,2	

Table B.7 Average of accuracies, obtained for user 3

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	77,8	61,6	58,7	69,6	53,0	64,6	49,7	63,4	68,5	70,5	60,5	69,6	73,1	62,7	31,1	69,8	70,3	54,8	68,7	66,1	72,0	41,1	77,3	45,0	46,5	42,8	61,1
	16	81,6	72,7	58,2	63,5	54,7	64,1	56,9	58,8	72,0	76,2	55,2	63,6	65,3	80,3	29,0	79,8	65,6	50,5	54,5	50,9	50,9	46,3	53,7	43,3	43,8	35,8	58,7
	10	70,3	63,5	50,0	90,7	65,7	66,8	53,1	49,1	59,6	76,5	57,7	62,5	55,5	84,7	21,7	83,6	72,9	44,1	70,7	63,1	77,6	38,9	56,5	38,7	47,8	27,3	59,6
	19	75,8	60,8	65,2	64,2	54,7	68,1	55,8	54,4	72,2	77,7	67,3	64,3	64,7	73,0	32,4	86,2	73,5	61,2	53,8	66,4	54,4	47,2	67,1	37,8	52,1	43,1	61,3
	27	**81,4**	**76,7**	**69,4**	**89,6**	**65,7**	**67,2**	**68,5**	**51,7**	**78,1**	**72,8**	**53,3**	**62,3**	**69,9**	**71,3**	**42,8**	**79,7**	**78,4**	**54,4**	**66,5**	**72,1**	**68,3**	**40,1**	**72,7**	**40,1**	**44,5**	**38,8**	**64,5**
Filters	None	57,1	63,8	67,6	58,2	60,0	68,7	47,4	41,7	57,3	69,6	70,2	64,1	39,1	77,7	41,7	91,7	76,4	56,1	51,3	51,1	62,6	47,4	73,7	44,7	41,9	38,5	58,4
	And	**75,6**	**61,9**	**62,6**	**64,4**	**60,1**	**67,7**	**58,9**	**52,6**	**66,4**	**84,2**	**58,9**	**71,2**	**73,4**	**69,6**	**32,1**	**73,3**	**73,0**	**53,0**	**70,5**	**70,6**	**64,3**	**41,8**	**62,9**	**41,1**	**53,7**	**28,7**	**61,2**
	Library	85,4	65,6	63,3	60,2	61,8	63,9	50,4	48,7	69,8	63,6	50,5	60,1	66,3	71,7	23,2	65,2	62,0	37,8	65,6	51,1	58,1	36,5	61,4	53,4	35,0	36,6	56,4
Average		75,6	65,8	61,9	70,0	59,5	66,4	55,1	52,5	68,0	73,9	59,2	64,7	63,4	73,9	31,8	78,7	71,5	51,5	62,7	61,4	63,5	42,4	65,7	43,0	45,7	36,5	

Table B.8 Average of approximations, obtained for user 3

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	85,1	94,0	84,4	84,2	90,2	90,1	92,5	87,8	80,5	95,9	80,9	81,5	76,9	83,6	88,8	91,4	93,9	94,5	80,5	87,4	80,7	94,8	75,5	93,4	79,5	78,6	86,4
	16	72,9	80,4	78,8	83,8	70,7	82,2	78,6	80,6	80,6	76,0	82,8	63,3	65,4	75,6	76,0	77,0	80,8	81,1	67,7	77,7	86,7	71,0	79,4	75,7	78,5	72,0	76,7
	10	69,9	61,2	63,2	70,2	70,1	58,9	66,9	55,2	67,8	68,6	71,7	58,8	54,5	62,6	63,1	68,0	62,1	56,8	72,7	66,5	70,2	71,2	64,5	67,6	54,9	57,7	64,4
	19	73,6	80,1	84,8	89,3	85,6	73,0	74,7	68,9	74,7	80,4	71,4	66,1	71,4	70,9	74,1	83,2	70,8	79,0	75,3	82,7	76,7	70,4	86,9	80,9	85,7	77,2	77,2
	27	**75,2**	**90,8**	**88,7**	**93,7**	**84,5**	**72,0**	**78,7**	**89,4**	**84,3**	**75,0**	**78,8**	**78,6**	**76,7**	**74,9**	**79,7**	**73,4**	**76,7**	**90,9**	**80,4**	**82,6**	**88,2**	**72,0**	**79,6**	**72,6**	**81,7**	**73,9**	**80,5**
Filters	None	85,1	100,0	94,2	89,9	99,4	93,2	90,8	100,0	96,8	89,3	89,1	86,8	84,6	96,3	83,3	87,8	88,4	92,9	86,2	83,4	89,8	99,9	99,2	100,0	89,2	88,1	91,7
	And	**75,8**	**68,8**	**59,1**	**69,3**	**59,8**	**61,8**	**63,8**	**55,7**	**72,4**	**69,0**	**66,7**	**59,4**	**65,6**	**60,6**	**60,2**	**65,5**	**61,0**	**59,7**	**72,8**	**69,9**	**68,8**	**71,9**	**74,0**	**67,1**	**70,1**	**69,5**	**66,1**
	Library	69,9	86,2	69,2	77,9	69,9	70,8	73,8	78,0	85,0	74,1	71,1	62,0	69,5	56,6	61,0	71,9	67,0	78,6	73,7	79,0	68,9	65,7	72,6	68,9	71,5	80,6	72,1
Average		75,9	82,7	77,8	82,3	78,8	75,3	77,5	77,0	80,3	78,5	76,6	69,6	70,6	72,6	73,3	77,3	75,1	79,2	76,2	78,6	78,8	77,1	79,0	78,3	76,4	74,7	

Table B.9 Average of approximation differences, obtained for user 3

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	2,8	2,4	2,3	4,3	6,7	2,2	3,3	3,3	2,3	2,5	4,5	4,6	3,5	3,4	7,9	0,9	5,3	3,7	3,6	2,2	2,3	3,2	2,1	4,3	6,3	4,7	3,6
	16	1,5	0,5	4,5	3,3	4,7	3,0	0,3	5,7	2,2	4,3	2,3	3,3	3,0	4,2	6,2	1,7	6,2	3,8	2,8	2,0	4,9	2,8	3,5	1,3	4,8	5,7	3,4
	10	3,8	1,1	2,8	3,9	1,3	3,1	3,3	4,4	1,5	1,6	5,3	4,8	3,6	1,1	3,6	1,4	2,4	5,1	2,9	0,1	4,1	2,3	3,7	1,9	2,1	3,5	2,9
	19	0,1	3,4	3,4	5,8	6,6	3,5	1,6	5,5	3,7	3,1	4,7	2,7	2,1	3,2	7,6	1,2	6,8	6,0	1,1	1,6	2,4	4,7	0,0	4,3	4,5	4,6	3,6
	27	**3,4**	**1,4**	**5,7**	**2,9**	**3,9**	**3,1**	**0,6**	**4,8**	**2,5**	**1,5**	**2,1**	**2,8**	**3,9**	**2,0**	**4,3**	**0,0**	**4,5**	**4,2**	**1,1**	**1,7**	**4,2**	**4,5**	**0,9**	**3,2**	**7,6**	**5,5**	**3,2**
Filters	None	1,1	2,9	2,8	1,5	0,2	2,1	0,0	2,6	2,7	0,0	1,1	0,0	1,4	1,9	2,5	0,0	1,3	0,7	1,4	1,7	1,0	2,0	1,8	0,0	0,7	0,1	1,3
	And	**0,3**	**0,5**	**2,5**	**4,5**	**2,6**	**4,5**	**1,3**	**6,5**	**4,2**	**4,2**	**2,1**	**4,5**	**3,7**	**3,3**	**7,2**	**0,0**	**5,4**	**3,7**	**2,8**	**2,6**	**4,9**	**5,1**	**0,3**	**2,5**	**5,2**	**5,4**	**3,5**
	Library	3,6	2,7	7,1	5,6	7,1	2,9	1,5	4,7	6,1	5,4	4,5	8,9	4,6	4,9	10,5	1,3	8,5	5,8	3,3	4,1	4,2	7,1	3,2	3,2	10,6	7,4	5,3
Average		2,1	1,8	3,9	4,0	4,1	3,1	1,5	4,7	3,2	2,8	3,3	4,0	3,2	3,0	6,2	0,8	5,0	4,1	2,4	2,0	3,5	4,0	2,0	2,6	5,2	4,6	

Table B.10 Average of accuracies, obtained for user 4

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	77,0	67,1	73,6	69,6	45,3	51,7	52,5	59,9	68,7	73,5	58,3	72,1	70,3	68,4	37,2	68,8	60,0	56,0	55,9	53,2	67,2	35,2	74,8	48,1	42,0	44,7	59,7
	16	75,0	67,6	59,2	62,1	55,5	65,7	54,5	54,3	80,1	81,9	82,6	64,1	57,4	74,6	27,9	82,6	61,5	51,0	54,4	65,1	51,3	49,3	55,6	42,1	42,4	40,4	59,9
	10	68,1	58,3	53,4	68,3	63,8	65,6	53,0	45,0	61,4	80,0	57,8	65,4	53,9	73,6	21,8	79,0	69,4	44,8	72,5	66,8	61,7	34,8	56,6	46,0	50,2	30,7	57,8
	19	74,2	59,0	60,7	48,1	58,3	70,0	58,4	58,0	77,0	71,5	49,5	66,8	61,9	78,8	32,1	84,2	76,5	56,7	72,0	75,1	73,5	47,1	59,6	52,8	46,4	43,0	62,0
	27	**81,6**	**74,2**	**70,6**	**62,9**	**58,0**	**77,7**	**47,8**	**61,2**	**75,8**	**72,4**	**57,3**	**86,7**	**63,2**	**73,3**	**35,0**	**70,8**	**69,6**	**65,0**	**71,4**	**69,8**	**73,3**	**46,1**	**68,5**	**44,7**	**47,9**	**35,9**	**63,9**
Filters	**None**	**79,2**	**69,1**	**59,0**	**73,0**	**65,7**	**68,7**	**43,7**	**57,7**	**73,5**	**75,7**	**50,1**	**70,4**	**51,3**	**78,8**	**38,9**	**86,2**	**73,8**	**55,8**	**56,9**	**74,8**	**66,7**	**54,9**	**66,3**	**48,7**	**51,5**	**42,5**	**62,8**
	And	74,1	69,2	67,6	66,3	51,7	60,6	51,7	51,0	67,5	82,6	56,6	66,5	85,6	71,0	33,5	66,5	65,5	57,6	70,3	67,1	71,8	48,0	63,6	39,5	52,9	47,4	61,8
	Library	73,3	67,0	64,2	68,6	61,9	66,4	52,4	56,5	68,7	75,9	48,9	64,4	74,9	72,7	33,2	73,7	75,0	54,2	65,7	57,0	67,7	41,2	60,3	45,2	37,6	36,0	60,1
Average		75,3	66,4	63,5	64,9	57,5	65,8	51,7	55,5	71,6	76,7	57,6	69,6	64,8	73,9	32,4	76,5	68,9	55,1	64,9	66,1	66,7	44,6	63,2	45,9	46,4	40,1	

Table B.11 Average of approximations, obtained for user 4

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	85,4	92,9	80,0	88,2	76,7	87,8	95,0	83,9	89,8	91,1	90,3	89,0	76,6	76,6	90,7	72,4	93,1	88,9	86,4	93,3	76,6	89,2	76,1	92,4	83,7	95,1	86,2
	16	82,8	73,6	72,8	72,9	73,5	68,3	73,0	71,6	81,3	80,2	76,0	75,5	71,7	74,9	69,1	77,2	77,7	67,3	77,4	77,6	77,7	64,7	72,3	66,9	78,9	64,2	73,8
	10	66,3	67,8	72,3	79,6	70,9	54,3	71,0	65,0	69,7	60,5	72,8	66,9	68,4	70,8	58,3	60,6	62,5	63,6	62,9	67,3	74,7	65,4	55,7	65,4	53,9	54,5	65,4
	19	77,2	74,5	84,1	80,1	85,8	67,9	71,6	76,0	85,7	80,9	84,0	74,9	83,1	76,1	82,9	71,9	80,0	86,5	91,8	83,2	79,9	71,0	86,9	68,0	85,6	86,9	79,9
	27	**76,8**	**83,0**	**85,0**	**77,2**	**81,9**	**71,3**	**91,4**	**90,9**	**93,6**	**74,7**	**75,1**	**70,1**	**75,7**	**68,2**	**78,2**	**77,0**	**78,9**	**85,9**	**83,5**	**87,5**	**83,7**	**80,7**	**85,8**	**86,0**	**79,2**	**89,7**	**81,2**
Filters	**None**	**86,8**	**99,5**	**88,4**	**89,4**	**93,8**	**83,8**	**100,0**	**89,9**	**87,8**	**95,0**	**91,2**	**90,9**	**82,1**	**87,3**	**98,4**	**93,3**	**88,1**	**85,8**	**100,0**	**96,1**	**100,0**	**88,9**	**93,7**	**98,3**	**85,2**	**88,5**	**91,6**
	And	62,9	74,3	54,4	67,0	68,0	64,5	77,8	59,3	60,5	55,9	62,8	62,3	52,8	62,8	64,2	59,0	56,4	58,7	66,1	72,0	74,2	65,0	70,5	55,0	56,7	70,1	63,6
	Library	78,5	82,2	63,7	67,7	70,6	76,9	74,1	71,7	73,0	82,3	76,1	76,6	70,9	62,7	69,4	67,7	66,2	76,0	82,5	80,1	73,0	73,6	65,7	71,4	82,2	77,6	73,6
Average		77,1	81,0	75,1	77,8	77,6	71,8	81,7	76,0	80,2	77,6	78,5	75,8	72,7	72,4	76,4	72,4	75,4	76,6	81,3	82,1	80,0	74,8	75,8	75,4	75,7	78,3	

Table B.12 Average of approximation differences, obtained for user 4

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	0,5	1,3	5,5	2,8	5,8	2,4	1,1	4,3	3,5	2,9	3,7	5,5	1,9	1,6	5,9	2,2	4,8	2,3	4,1	3,1	1,8	5,6	3,7	2,2	4,7	3,5	3,3
	16	2,0	0,3	4,8	3,1	5,5	2,4	2,2	4,7	3,8	3,8	5,3	4,0	2,2	3,2	5,7	2,1	5,5	4,9	3,5	0,4	3,9	3,0	0,4	1,7	5,8	3,0	3,4
	10	3,5	1,0	2,3	2,9	1,5	4,4	3,9	3,0	2,7	3,5	3,8	5,3	3,9	2,9	3,7	2,6	2,2	4,8	3,4	0,8	4,1	2,9	1,9	0,9	2,5	3,1	3,0
	19	1,3	3,1	3,0	5,3	5,7	5,4	0,4	5,1	5,1	3,8	3,3	2,8	4,3	1,8	5,7	1,3	5,0	4,7	3,1	2,9	2,7	3,8	0,6	3,0	4,0	2,8	3,5
	27	**1,8**	**3,5**	**6,2**	**5,3**	**5,7**	**1,5**	**2,9**	**2,8**	**3,7**	**4,2**	**5,3**	**4,3**	**2,9**	**2,2**	**4,9**	**0,0**	**7,1**	**4,0**	**0,8**	**0,7**	**4,3**	**3,7**	**1,0**	**1,2**	**4,1**	**6,7**	**3,5**
Filters	**None**	**0,0**	**0,0**	**2,9**	**1,6**	**2,9**	**0,7**	**0,2**	**0,4**	**0,0**	**0,0**	**0,0**	**1,1**	**0,3**	**0,7**	**0,2**	**1,5**	**1,0**	**0,7**	**0,5**	**0,5**	**1,3**	**0,0**	**2,4**	**1,1**	**1,5**	**3,1**	**0,9**
	And	1,9	3,0	4,3	1,5	5,5	4,5	1,8	3,3	3,5	4,0	3,7	4,5	3,8	4,8	5,9	3,1	3,9	3,8	2,2	1,8	3,9	2,1	1,1	1,0	6,1	6,8	3,5
	Library	2,6	4,5	6,0	8,6	7,5	4,2	2,1	6,3	3,3	5,7	7,4	9,0	6,0	6,5	6,9	2,0	9,5	6,4	5,1	2,3	7,4	7,9	1,9	4,9	8,1	6,3	5,7
Average		1,7	2,1	4,4	3,9	5,0	3,2	1,8	3,8	3,2	3,5	4,0	4,6	3,2	3,0	4,9	1,9	4,9	3,9	2,8	1,6	3,7	3,6	1,6	2,0	4,6	4,4	

Table B.13 Average of accuracies, obtained for all users

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	78,1	64,0	69,9	65,7	54,8	64,3	52,8	60,5	68,0	68,2	59,1	70,4	71,9	68,3	33,7	70,0	67,3	54,3	66,5	64,8	70,2	35,6	77,4	45,6	44,0	45,6	61,2
	16	77,9	65,9	59,9	64,5	57,1	65,2	57,4	55,9	76,1	74,9	64,3	63,7	61,8	78,8	30,5	82,1	65,3	48,0	55,7	54,7	52,6	49,3	55,4	44,6	42,4	37,8	59,3
	10	67,4	61,2	53,3	74,9	66,6	65,9	50,4	47,8	59,8	76,0	56,5	65,2	57,2	77,1	24,6	80,0	65,9	43,2	70,6	62,5	65,1	37,1	55,2	43,0	46,7	29,6	57,8
	19	75,6	61,3	63,1	62,0	58,0	65,9	55,3	56,0	76,5	76,0	59,6	65,3	63,3	75,5	34,1	82,6	74,0	58,2	66,9	71,2	67,6	42,5	66,3	46,7	49,2	41,9	62,1
	27	**80,3**	**76,4**	**69,1**	**70,3**	**60,4**	**71,6**	**56,4**	**56,2**	**74,2**	**74,4**	**58,3**	**70,5**	**66,6**	**74,0**	**35,1**	**76,0**	**74,1**	**55,1**	**70,0**	**70,1**	**71,1**	**41,3**	**69,5**	**46,8**	**46,2**	**37,2**	**63,5**
Filters	**None**	**72,2**	**65,7**	**64,0**	**69,5**	**62,8**	**70,3**	**47,1**	**54,5**	**68,1**	**71,1**	**62,8**	**65,3**	**48,5**	**79,1**	**39,9**	**91,0**	**75,7**	**56,4**	**62,1**	**67,4**	**64,9**	**50,3**	**70,7**	**48,3**	**48,7**	**46,0**	**62,4**
	And	73,5	68,5	65,8	63,9	57,9	64,3	55,9	51,4	69,6	83,8	57,3	70,6	76,5	71,6	30,6	71,4	69,0	54,9	69,5	69,9	68,1	42,2	64,1	40,8	56,3	34,2	61,6
	Library	79,1	66,8	65,0	64,1	62,7	66,3	52,9	53,4	68,5	69,6	50,5	61,4	69,8	73,8	27,5	69,2	67,2	45,7	66,1	54,1	65,5	37,5	65,2	46,3	33,7	34,0	58,3
Average		75,5	66,2	63,7	66,9	60,1	66,7	53,5	54,5	70,1	74,3	58,5	66,6	64,5	74,8	32,0	77,8	69,8	52,0	65,9	64,3	65,6	42,0	65,5	45,3	45,9	38,3	

Table B.14 Average of approximations, obtained for all users

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	87,1	88,7	81,3	87,7	83,6	84,8	90,3	83,3	86,2	88,3	84,4	82,0	77,7	79,4	86,3	84,1	88,3	87,7	89,0	90,1	84,3	87,8	78,7	87,1	84,3	87,3	85,4
	16	78,5	79,3	76,6	78,5	73,9	71,9	78,7	72,6	79,3	75,3	76,4	68,1	67,2	75,2	74,6	77,1	77,1	74,3	75,8	75,2	79,3	73,0	73,3	70,3	76,7	68,8	74,9
	10	69,3	66,9	68,2	73,1	68,2	60,6	67,8	62,3	66,2	65,2	69,9	62,8	61,7	67,5	59,2	67,4	64,0	64,2	67,7	68,5	70,3	64,9	61,7	61,3	59,7	60,4	65,3
	19	78,1	77,2	82,6	81,7	80,4	72,0	77,1	73,5	80,1	79,1	80,0	72,4	77,3	73,2	76,7	78,6	77,3	80,0	83,4	83,6	82,0	74,8	84,7	76,3	81,2	80,4	78,6
	27	**80,9**	**83,3**	**85,7**	**83,8**	**81,3**	**74,2**	**86,8**	**87,9**	**85,3**	**77,8**	**80,3**	**78,8**	**76,3**	**72,1**	**78,0**	**77,8**	**79,2**	**88,1**	**82,7**	**81,6**	**84,8**	**78,0**	**81,7**	**77,3**	**78,5**	**81,9**	**80,9**
Filters	**None**	**91,5**	**95,3**	**92,0**	**92,8**	**93,9**	**90,0**	**96,3**	**94,8**	**94,8**	**91,8**	**89,6**	**92,1**	**85,3**	**90,9**	**90,4**	**91,5**	**89,2**	**89,3**	**94,7**	**89,9**	**92,8**	**95,3**	**96,6**	**97,9**	**89,2**	**88,4**	**92,2**
	And	66,9	68,3	57,7	68,9	64,3	61,2	70,1	59,3	66,7	62,4	67,6	59,3	57,3	59,9	60,3	61,8	59,5	64,4	69,2	71,1	70,1	67,2	70,8	62,6	64,1	69,3	64,6
	Library	76,0	79,4	70,2	76,9	70,2	72,5	74,3	73,8	76,6	75,9	76,3	68,8	68,6	63,8	66,8	71,7	68,2	76,9	77,8	76,0	71,1	71,5	71,7	68,4	73,1	77,6	72,8
Average		78,5	79,8	76,8	80,4	77,0	73,4	80,2	75,9	79,4	77,0	78,1	73,0	71,4	72,7	74,0	76,3	75,3	78,1	80,1	79,5	79,3	76,5	77,4	75,2	75,8	76,8	

Table B.15 Average of approximation differences, obtained for all users

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Avg.
Variation	39	1,7	1,8	4,2	3,5	5,3	2,4	1,9	3,8	3,1	3,3	4,1	4,9	3,4	3,1	6,5	1,2	5,3	3,5	3,6	2,6	2,5	4,2	2,7	2,8	6,5	4,1	3,5
	16	1,4	0,7	4,4	4,3	5,2	3,6	1,6	4,6	3,6	3,5	3,8	3,5	2,9	3,5	5,8	1,8	5,4	4,1	3,0	1,5	3,9	2,9	1,4	2,3	4,9	4,2	3,4
	10	2,6	2,0	3,0	3,6	2,2	3,6	3,1	4,3	2,9	2,4	4,5	4,7	3,5	1,7	3,8	1,6	3,6	4,0	2,4	1,3	3,4	3,3	2,7	2,1	3,0	3,6	3,0
	19	1,3	3,1	3,5	5,1	5,4	4,0	1,3	4,3	4,2	3,8	4,4	3,5	3,3	2,5	6,6	1,4	5,5	4,5	2,3	2,4	2,9	4,3	0,7	3,1	4,3	4,0	3,5
	27	**2,0**	**2,7**	**5,1**	**4,2**	**4,6**	**2,9**	**1,6**	**4,5**	**3,1**	**3,2**	**3,6**	**3,9**	**2,9**	**2,8**	**4,8**	**0,6**	**5,8**	**4,1**	**1,3**	**1,8**	**3,5**	**4,6**	**0,9**	**2,6**	**5,7**	**5,0**	**3,4**
Filters	**None**	**1,0**	**1,4**	**1,8**	**1,7**	**1,4**	**1,5**	**0,4**	**1,6**	**0,9**	**0,9**	**1,1**	**0,9**	**1,3**	**1,1**	**2,0**	**0,5**	**1,4**	**1,5**	**0,7**	**1,1**	**1,3**	**1,6**	**1,2**	**0,5**	**1,0**	**1,6**	**1,2**
	And	1,8	1,4	3,3	3,1	4,1	4,0	2,4	4,6	4,1	3,7	3,7	4,1	2,7	3,5	6,0	1,3	4,4	3,9	2,8	2,6	3,9	3,6	1,4	2,3	5,5	6,0	3,5
	Library	2,9	3,8	7,0	7,6	7,5	3,8	2,4	5,8	5,3	5,5	5,9	7,8	4,9	5,8	8,7	2,0	8,7	7,0	3,3	3,3	6,0	6,9	2,6	4,0	8,9	7,1	5,5
Average		1,8	2,1	4,0	4,1	4,5	3,2	1,9	4,2	3,4	3,3	3,9	4,1	3,1	3,0	5,5	1,3	5,0	4,1	2,4	2,1	3,4	3,9	1,7	2,5	5,0	4,4	

Appendix C – Serious Game Validation Questionnaire

Overall

	1	2	3	4	5	6	7	8	9	10
Did you enjoy playing Kinect-Sign?										
Is the game useful to learn sign language?										
Did you find the game interface suitable?										
Are the game controllers adequate?										
• *Mouse & Keyboard?*										
• *Kinect Sensor?*										
Did you find the game concept interesting?										
Will you be coming back for more?										
Do you want to learn more about sign language?										

Lessons

	1	2	3	4	5	6	7	8	9	10
Did you enjoy the lessons?										
Are the lessons adequate to teach sign language?										
Are they easy to understand?										
Did you find the lesson interface suitable?										
Are the game controllers adequate for the lesson?										
• *Mouse & Keyboard?*										
• *Kinect Sensor?*										

Games

	1	2	3	4	5	6	7	8	9	10
Are the games adequate to the lessons learned?										
Are the games easy to understand?										
Did you have fun playing them?										
Did you find the game interface suitable?										
Are the game controllers adequate for the games?										
• *Mouse & Keyboard?*										
• *Kinect Sensor?*										
Would you find interesting to play other classic games adapted to PSL?										